AFML-TR-79-4081



# ENVIRONMENTAL DURABILITY OF THE WELDBOND, FPL, AND PABST JOINING SYSTEMS

Northrop Corporation
Aircraft Group
3901 West Broadway
Hawthorne, California 90250



JULY 1979



FINAL REPORT FOR PERIOD DEC 1977 – MAY 1979

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FOR THE COMMANDER

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| REPORT DOCUMENTATION PAGE | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|
| 1. REPORT NUMBER: AFML-TR-79-4081 | 2. GOVT ACCESSION NO. / 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle): ENVIRONMENTAL DURABILITY OF THE WELDBOND, FPL AND PABST JOINING SYSTEMS | 5. TYPE OF REPORT & PERIOD COVERED: Final Report, 1 Dec 77 - 31 May 1979 |
| | 6. PERFORMING ORG. REPORT NUMBER: NOR-79-41 |
| 7. AUTHOR(s): R. G. Hocker | 8. CONTRACT OR GRANT NUMBER(s): F33615-76-C-5412 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS: Northrop Corporation, 3901 W. Broadway, Hawthorne, CA 90250 | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Project No. 828-6 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, OH 45433 | 12. REPORT DATE: July 79 |
| | 13. NUMBER OF PAGES: 70 |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) | 15. SECURITY CLASS. (of this report): UNCLASSIFIED |
| | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Weldbonding, surface treatment, durability, environmental stress-corrosion, spot welding, aluminum adhesive bonding

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This program was conducted as an addendum to Contract No. F33615-76-C-5412, "Advanced Weldbonding Process Establishment for Aluminum". Under controlled stress and environmental conditions, a direct comparison of durability and surface corrosion behavior was made for three surface preparation/adhesive systems. These systems included the PABST adhesive bonding system, the FPL adhesive bonding system, and the Northrop weldbond system. The three types of tests used were the wedge test, the constant load-salt water immersion CONT →

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CONT

test, and the surface scratch test. Four different environmental exposures were used: (1) 95 to 100 percent relative humidity at 120F, (2) 5 percent salt fog at 95F, (3) 3.5 percent salt water and (4) the sea coast beach site at El Segundo, California. Four material combinations were evaluated for this program: 2024-T3 alclad bonded to 7075-T6 bare, 2024-T3 bare bonded to 7075-T6 bare, 2024-T3 bare bonded to 2024-T3 bare, and 7075-T6 bare bonded to 7075-T6 bare.

The objective of this program was to rank the three bonding systems and four material combinations in terms of durability and corrosion behavior.

The results of this evaluation showed that the PABST system had the best durability, the FPL system was second, and the weldbond system was third in durability ranking. A separate Northrop IRAD program was conducted to improve the durability of the weldbond system. The results of this program showed that the addition of a thin, 0.00004 inch, layer of BR-127 primer (air dried then co-cured) to the standard weldbond surface improved its durability so that it is nearly equal to that of the PABST system and vastly superior to the commonly used FPL system. The corrosion behavior of the three surface preparation processes were equal when the surfaces were primed and painted.

The ranking of the four material combinations in terms of decreasing durability is as follows:

2024-T3 bare/2024-T3 bare
2024-T3 bare/7075-T6 bare
7075-T6 bare/7075-T6 bare
2024-T3 alclad/7075-T6 bare

## PREFACE

This report was prepared by the Northrop Corporation, Aircraft Group, Hawthorne, California, under USAF Contract No. F33615-76-C-5412, as an addendum to the basic weldbond program, "Advanced Weldbonding Process Establishment for Aluminum." The contract work was performed under Project No. 828-6 and was sponsored by the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Dayton, Ohio. Mr. S.G. Lee of the Metals Branch (LTM) of the Manufacturing Technology Division, AFML was the project engineer.

Northrop Corporation, Aircraft Group, was the contractor, with Mr. R.G. Hocker serving as the program manager for this addendum. Other Northrop personnel who made major contributions include: K. C. Wu, H. E. Langman, H. R. Miller, and J. W. Lewis (for welding and specimen preparation); V. S. Srinath, G. G. Richards, and L. M. Urzua (for surface preparation); and R. E. Herfert and S. L. Feenstra (for scanning electron microscope surface analysis).

McDonnell Douglas, Long Beach, California provided the PABST test panels and availability to their sea coast exposure site at El Segundo, California. The cooperation and assistance of the following McDonnell Douglas personnel is gratefully acknowledged: E. W. Thrall, Jr., PABST, Program Manager; R. W. Shannon, Materials and Process Engineering, Section Chief; R. W. Ochsner, Materials and Process Engineering, Unit Chief; and R. L. Radecky, Materials and Process Engineer.

The contractor report number is NOR-79-41. This report covers work performed from December 1977 through May 1979.

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## SECTION 1

## INTRODUCTION

During the past six years, two new processes have become available for surface treatment of aluminum prior to adhesive bonding. These are the 10-volt phosphoric acid anodizing process developed by Boeing, which has been integrated into the PABST (Primary Adhesively Bonded Structure Technology) program by McDonnell Douglas, (Reference 1) and the low-voltage dilute phosphoric acid/sodium dichromate anodizing process developed by Northrop (References 2, 3, and 4) for use in the weldbond manufacturing process. A third system for adhesive bonding, the FPL (Forest Products Laboratory) system, has been used extensively and is used presently by Fairchild Republic Corporation to adhesively bond panels for the A-10 aircraft. Reference made to the FPL system throughout this report is an abbreviated term for the bonding system in which an FPL etch is used with the BR-127 primer and the FM 123-2 mat adhesive.

The Northrop weldbond joining system was developed to have durability better than that of the spot weld etch joining system, which was previously used, and approximately equal to that of the FPL joining system. Comparison of the durability of these joining systems was based initially on a 1-day wedge test in 95-100 percent humidity at 120F. This test indicated only if a system was poor or good. A CL/SWIT (constant load-salt water immersion test) was then developed, which differentiated between a fair and a good system. At this stage of the test development, the weldbond system was shown to be equal or better than the FPL system. Currently, for the PABST system, long term wedge tests are used to evaluate durability. The long term wedge test differentiates between a good and an excellent adhesive bonding system. However, it does not evaluate the durability of the complete weldbond system since welds are not included in the preparation of the wedge test specimen; and yet, spot welding is an integral part of the weldbond joining system.

Northrop recently completed a program on "Advanced Weldbonding Process Establishment for Aluminum," (Reference 4). As part of this program, a technology transfer of the weldbond process to the Fairchild Republic Corporation was accomplished. A follow-on contract was awarded to Fairchild Republic to initiate production weldbonding of several fuselage panels for the A-10 aircraft.

One of the primary concerns in the use of adhesively bonded structures is premature failure due to a time-dependent crack growth in the bond joint under the combined influence of applied stress and a corrosive environment. This type of failure is commonly termed "environmental stress cracking." Resistance to environmental stress cracking is defined as environmental durability, and is referred to as durability in this report.

In order to compare the durability of the weldbond system with that of the other two adhesive bonding systems (PABST and FPL), an addendum program to the Northrop weldbonding contract (Reference 4) was conducted. Under controlled stress and environmental conditions, a direct comparison of durability behavior was made for the three systems. These systems included the PABST adhesive bonding system, the FPL adhesive bonding system, and the Northrop weldbond system.

A schematic representation of these systems is shown in Figure 1. The FPL system utilizes a thin (300 to 600 angstroms) boehmite layer ($\alpha Al_2O_3 \cdot H_2O$), which is formed during the FPL process. This bonding system also includes the BR-127 primer and the FM 123-2 mat adhesive. The weldbond system also utilizes a thin (400 to 800 angstroms) boehmite layer applied by anodizing, but this system does not include a primer. A chromated paste adhesive, Goodrich A1444B, is used for the weldbond system so that the welds can be made through the adhesive. The PABST adhesive system utilizes a much thicker (approximately 3,000 angstroms) boehmite layer and includes the BR-127 primer and the FM-73 mat adhesive. In order to evaluate these three joining systems, three different types of tests, including the wedge test, the constant load-salt water immersion test, and the surface scratch test, were used. Four different environmental exposures were used: (1) 95 to 100 percent relative humidity at 120F, (2) 5 percent salt fog at 95F, (3) 3.5 percent salt water at room temperature, and (4) the McDonnell Douglas sea coast beach site at El Segundo, California. Four material combinations were evaluated for this program: 2024-T3 alclad bonded to 7075-T6 bare, 2024-T3 bare bonded to 7075-T6 bare, 2024-T3 bare bonded to 2024-T3 bare, and 7075-T6 bare bonded to 7075-T6 bare.

The objective of this program was to rank the three bonding systems and the four material combinations in terms of durability behavior.

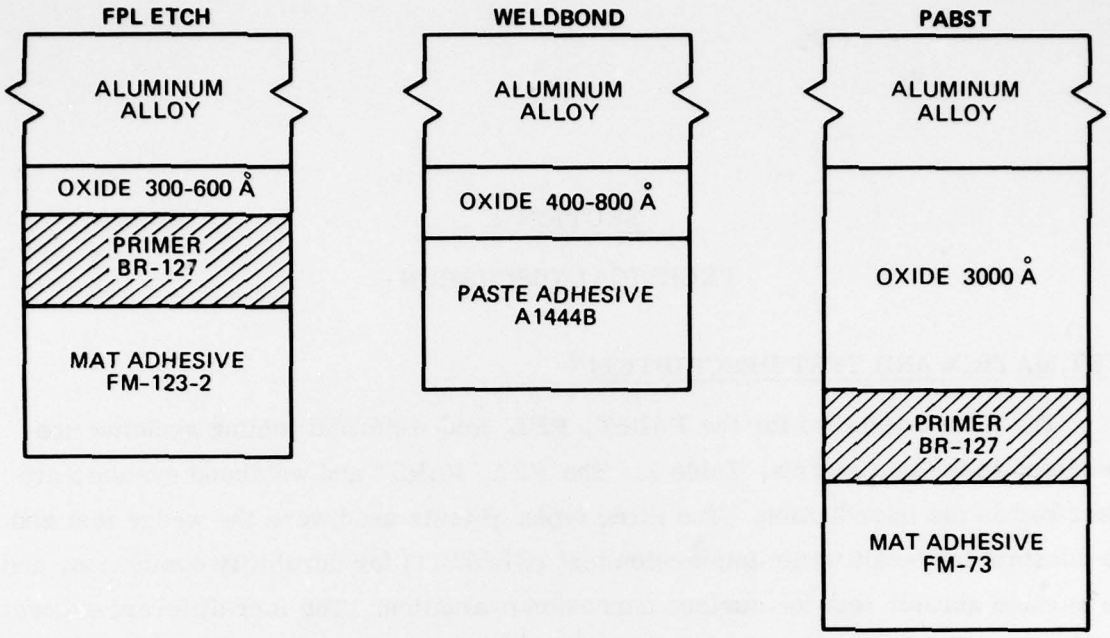



**FIGURE 1. SURFACE/ADHESIVE SYSTEMS FOR FPL, WELDBOND, AND PABST JOINING PROCESSES**

## SECTION 2

## TECHNICAL DISCUSSION

### TEST MATRIX AND TEST DESCRIPTION

The tests conducted for the PABST, FPL, and weldbond joining systems are presented in the test matrix, Table 1. The FPL, PABST and weldbond systems are described in the introduction. The three types of tests used were the wedge test and the constant load-salt water immersion test (CL/SWIT) for durability evaluation, and the surface scratch test for surface corrosion evaluation. The four different exposure environments include: 95 to 100 percent relative humidity at 120F, 5 percent salt fog at 95F per ASTM standard B117, 3.5 percent salt water at room temperature, and the McDonnell Douglas beach site located in El Segundo, California, approximately 75 yards from the ocean.

#### Wedge Test

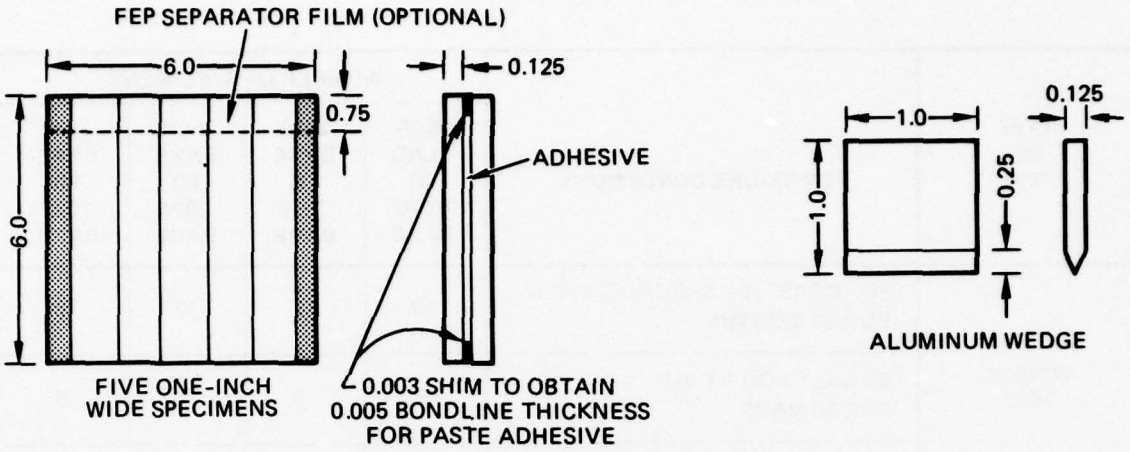
For the wedge tests, crack-growth measurements were made periodically for exposure times up to 90 days in the 95-100 percent relative humidity and salt fog environments, and once a month for a total of 1 year in the sea coast environment.

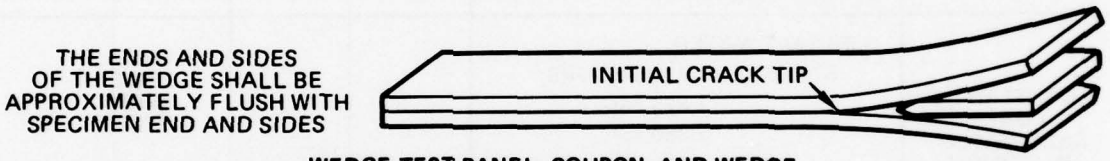
A sketch of the wedge coupon is shown in Figure 2. The wedge test panels measured 6 inches x 6 inches x 0.125 inch. The panels were cleaned, surface treated, and bonded, according to the procedures outlined in Tables 2, 3, and 4 for each of the three joining systems. After the cure cycle, all test panels were primed with MIL-P-23377 epoxy polyamide primer and painted with MIL-C-81773 polyurethane aircraft top coat paint. Ultrasonic inspections were made of each panel and only panels without voids in the adhesive bondline were accepted for tests. Five wedge coupons were saw cut from each 6-inch x 6-inch panel. One edge of each wedge specimen was machined or polished smooth so that wedge crack-growth measurements could easily be made. These edges were left unprotected throughout the exposure.

## TABLE 1. TEST MATRIX FOR EACH JOINING SYSTEM-FPL, WELDBOND, AND PABST

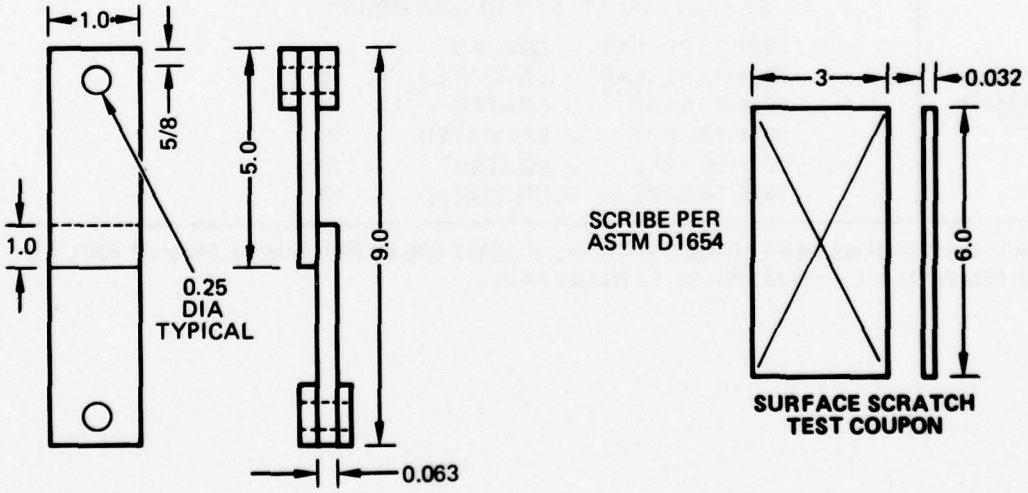
| TYPE OF TEST | EXPOSURE CONDITIONS | NUMBER OF SPECIMENS | | | |
|---|---|---|---|---|---|
| | | 2024 CLAD TO 7075 BARE | 2024 BARE TO 7075 BARE | 2024 BARE TO 2024 BARE | 7075 BARE TO 7075 BARE |
| WEDGE TEST | SEA COAST, EL SEGUNDO, CALIF FOR 12 MONTHS | 12 | 12 | 12 | 12 |
| | 5% SALT FOG AT 95F FOR 90 DAYS | 6 | 6 | 6 | 6 |
| | 95-100% RELATIVE HUMIDITY AT 120F FOR 90 DAYS | 6 | 6 | 6 | 6 |
| CONSTANT LOAD SALT WATER IMMERSION TEST | 3.5% SALT WATER STRESS FOR 2,000 HOURS: | | | | |
| | 1,875 PSI | 3 | 3 | 3 | – |
| | 2,380 PSI | – | – | – | 3 |
| | STRESS FOR 1,000 HOURS: | | | | |
| | 2,380 PSI | 3 | 3 | 3 | – |
| | 3,000 PSI | – | – | – | 3 |
| SURFACE SCRATCH TEST | 5% SALT FOG AT 95F FOR 2,000 HOURS | | | | |
| | 2024-T3 ALCLAD – COATED* – 10 | | | | |
| | 2024-T3 ALCLAD – UNCOATED – 10 | | | | |
| | 2024-T3 BARE – COATED* – 10 | | | | |
| | 2024-T3 BARE – UNCOATED – 10 | | | | |
| | 7075-T6 BARE – COATED* – 10 | | | | |
| | 7075-T6 BARE – UNCOATED – 10 | | | | |

*COATED SPECIMENS WERE PRIMED WITH MIL-P-23377 EPOXY POLYAMIDE PRIMER AND TOP COATED WITH MIL-C-81773 POLYURETHANE PAINT




WEDGE TEST PANEL, COUPON, AND WEDGE




NOTE: ALL DIMENSIONS ARE IN INCHES

**FIGURE 2. TEST COUPON CONFIGURATIONS**

## TABLE 2. FPL PROCESS

| OPERATION | MATERIAL | PROCESS |
|---|---|---|
| VAPOR DEGREASE | 1-1-1 TRICHLOROETHANE | |
| ALKALINE CLEAN | ALTREX 1097 5-8 OZ/GAL | 10-15 MINUTES 160-190F |
| SPRAY RINSE | DEIONIZED WATER | 5-7 MINUTES 110F |
| DEOXIDIZE AND ETCH | FPL-ETCH<br>96% SULFURIC ACID: 38.5-41.5 FLUID OZ/GAL<br>SODIUM DICHROMATE, DIHYDRATE: 8 OZ/GAL<br>2024 ALUMINUM SCRAP: 0.2 OZ/GAL | 12-15 MINUTES 150-160F |
| PRIME | BR-127, 0.00015-INCH TO 0.00030-INCH THICKNESS SPRAY COAT | AIR DRY: 30 MINUTES AT RT.<br>CURE: 60-120 MINUTES AT 250F |
| ADHESIVE | FM 123-2 0.045 LB/SQ FT, 2 LAYERS | VACUUM BAG. APPLY AUTOCLAVE PRESSURE OF 50-100 PSI.<br>CURE: 90 MINUTES AT 260F |

## TABLE 3. NORTHROP WELDBOND PROCESS

| OPERATION | MATERIAL | PROCESS |
|---|---|---|
| VAPOR DEGREASE | 1-1-1 TRICHLOROETHANE | VAPOR 60 SECONDS; CONDENSED FLUID-60 SECONDS; COOL, REPEAT. |
| ALKALINE CLEAN | TURCO 4215-S, 6-8 OZ/GAL SOLUTION | 12-15 MINUTES, 125-165F |
| SPRAY RINSE | COLD DEIONIZED WATER WITH TAP WATER MIX | 5-7 MINUTES |
| DEOXIDIZE | NITRIC ACID/AMCHEM-7 (MODIFIED)<br>NITRIC ACID – 11-14% BY VOLUME, BE° 42 (70% $HNO_3$)<br>AMCHEM-7: 2.9 – 3.3 WT OZ/GALLON SOLUTION<br>ALODINE-45: 11.2 – 11.5 ML/GALLON SOLUTION<br>ALODINE 1200E ACTIVATOR – 13.2 – 13.4 ML/GALLON SOLUTION<br>BALANCE – DI WATER | 6-8 MINUTES, ROOM TEMPERATURE IN AGITATED SOLUTION |
| SPRAY RINSE | COLD DEIONIZED WATER WITH TAP WATER MIX | 5-7 MINUTES |
| ANODIZE | PSD SOLUTION<br>PHOSPHORIC ACID – 1.2 – 1.5 FL OZ/ GALLON SOLUTION (85% $H_3PO_4$)<br>SODIUM DICHROMATE DIHYDRATE: – 1.3 – 1.5 OZ/GALLON SOLUTION | 20-25 MINUTES, ROOM TEMPERATURE<br>VOLTAGE – 1.4-1.6 VOLTS, DC FOR BARE ALLOYS<br>0.9-1.1 VOLTS, DC FOR CLAD ALLOYS |
| SPRAY RINSE | COLD DEONIZED WATER WITH TAP WATER MIX | 5-7 MINUTES |
| OVEN DRY | CIRCULATING HOT AIR | 30-40 MINUTES, 150± 10F |
| ADHESIVE | A1444B PASTE | APPLY TO BOTH SURFACES |
| WELD | | RESISTANCE SPOT WELD |
| CURE | | 250-260F FOR 2 HOURS |

## TABLE 4. PABST PROCESS

| OPERATION | MATERIAL | PROCESS |
|---|---|---|
| VAPOR DEGREASE OR SOLVENT WIPE | 1-1-1 TRICHLOROETHANE | |
| ALKALINE CLEAN | TURCO 4215-S | 4-8 OZ/GAL<br>15 MINUTES<br>140F |
| SPRAY RINSE | DEIONIZED WATER | 5-7 MINUTES<br>ROOM TEMPERATURE |
| DEOXIDIZE | NITRIC ACID/AMCHEM 6-16 | 15 MINUTES |
| | AMCHEM 6-16: 6-8% BY VOLUME<br>8-10% BY WEIGHT | 75-95F |
| | NITRIC ACID: 20 FLUID OZ/GAL, (70% $HNO_3$) | |
| | DEIONIZED WATER: BALANCE | |
| SPRAY RINSE | DEIONIZED WATER | 5-7 MINUTES<br>ROOM TEMPERATURE |
| ANODIZE | PHOSPHORIC ACID | 20-25 MINUTES<br>ROOM TEMPERATURE<br>AT 10-15 VOLTS |
| | 96% $H_3PO_4$: 11-16 OZ/GAL<br>DEIONIZED WATER: BALANCE | |
| SPRAY RINSE | DEIONIZED WATER | 5-7 MINUTES<br>ROOM TEMPERATURE |
| OVEN DRY | CIRCULATING HOT AIR | 30-60 MINUTES<br>150-160F |
| PRIME: | BR-127, 0.00015-INCH TO 0.00030-INCH THICKNESS SPRAY COAT | AIR DRY: 30 MINUTES AT RT<br>CURE: 1 HOUR AT 225F |
| ADHESIVE: | FM 73, 0.060 LB/SQ FT | VACUUM BAG APPLY AUTOCLAVE PRESSURE OF 50-100 PSI. CURE: 90 MINUTES AT 250F |

On the day the specimens were to be exposed, an aluminum wedge was driven into one end of the specimen, as shown in Figure 2. A 3X magnifying glass was used to determine the initial crack length and a scribe mark was made on the edge of the specimen. The initial crack length and the adhesive bondline thickness were measured and recorded. . A high stress was created at the initial crack tip along the bondline across the one-inch wide specimen. During exposure to the corrosive environment, the crack progressed uniformly toward the bottom end of the wedge specimen. The progression of the crack, or crack-growth, was easily measured by placing a steel ruler along the edge of the specimen using the initial crack length scribe mark as the reference line. Measurements were made to the nearest 0.01 inch.

Constant Load-Salt Water Immersion Test (CL/SWIT)

A sketch of the constant load-salt water immersion specimen is shown in Figure 2. For this test specimen, a sheet thickness of 0.063 inch was used. Doublers of the same thickness were also used at the ends of the specimen to prevent failure at the pin loading holes.

In order to obtain 10 one-inch wide specimens from one bonded panel, 5-inch x 12-inch panels were cleaned, surface treated, and adhesive bonded or weldbonded with a one-inch overlap joint. X-ray analysis was made of the weldbonded panels to confirm that high quality welds existed at the lap-joint. These panels were then primed and top coated using the same materials as used for the wedge test panels. Ten specimens were cut from each panel and the edges were machined smooth. These edges were left unprotected during the test.

Four control tests were conducted for each material combination shown in Table 1, in order to establish baseline lap-shear strengths. To provide the salt water environment, a slit was made in the bottom of a small, open plastic bottle so that the specimen could be pulled through the bottom of the bottle. The slit was then sealed which allowed the lap-joint to be immersed in a salt water solution. After the specimens were loaded in the constant load creep frame, a 3.5 percent salt water solution was poured into the bottle. This solution was replaced once a week during the 1,000 hour and 2,000 hour exposures. For the 1,000 hour exposure, the specimens were stressed at loads which were equal to 60 percent of the ultimate tensile strength of the lowest strength aluminum alloy used in the joint. For the 2,000 hour exposure, the specimens were stressed at loads which were equal to 48 percent of the ultimate tensile strength of the lowest strength aluminum alloy used in the joint. The relationships of the

constant load to the percent ultimate strength and to the percent yield strength, based on MIL-Hdbk-5 "A" values, for each material are as follows:

| | FTU (psi) | FTY (psi) | Exposure Time (Hours) | Constant Load (lbs) | Percent FTU | Percent FTY |
|---|---|---|---|---|---|---|
| 2024-T3 alclad | 62,000 | 45,000 | 2,000 | 1,875 | 48 | 66 |
| | | | 1,000 | 2,380 | 61 | 84 |
| 2024-T3 bare | 65,000 | 47,000 | 2,000 | 1,875 | 46 | 63 |
| | | | 1,000 | 2,380 | 58 | 80 |
| 7075-T6 bare | 78,000 | 70,000 | 2,000 | 2,380 | 48 | 54 |
| | | | 1,000 | 3,000 | 61 | 68 |

After the CL/SWIT specimens completed the constant load-salt water immersion exposure, they were lap-shear tested to determine if there was any loss in strength or any corrosion attack at the joint. These lap-shear strength values were compared to the control lap-shear strength of unexposed specimens.

Surface Scratch Test

The third test, which was used to evaluate the general surface corrosion behavior of the three joining systems, was the surface scratch test. The test specimen is shown in Figure 2. Three-inch x 6-inch panels were used for this test. Half of the specimens were uncoated and half were primed and top coated as shown in Table 1. An "X" was scribed on the surfaces of these panels with a Stanley knife, as defined in ASTM standard D 1654, "Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments." The test panels were exposed to 5 percent salt fog at 95F for 2,000 hours. Alodined control specimens for each of the alloys were also exposed. Periodically, the specimens were examined for evidence of corrosion at the scratch and on the surface.

## SURFACE PREPARATION AND ADHESIVE APPLICATION

The aluminum surfaces were cleaned, deoxidized, and anodized, according to the process descriptions shown in Tables 2, 3, and 4. The type of adhesive and cure cycles used are also shown in these tables. The FPL process and the weldbond process were accomplished at Northrop, and the PABST test panels were surface treated and adhesively bonded at McDonnell Douglas at Long Beach, California. Scanning electron

microscope (SEM) analysis on bent specimens was used to determine the thickness of the oxide layer and to provide assurance that the proper surface treatment was achieved. The SEM samples were processed at the same time as the test panels. Typical anodized layers for each material are shown in Figures 3, 4, and 5 for all three surface treatments. The thicknesses of the oxide layers were within the range noted in Figure 1.

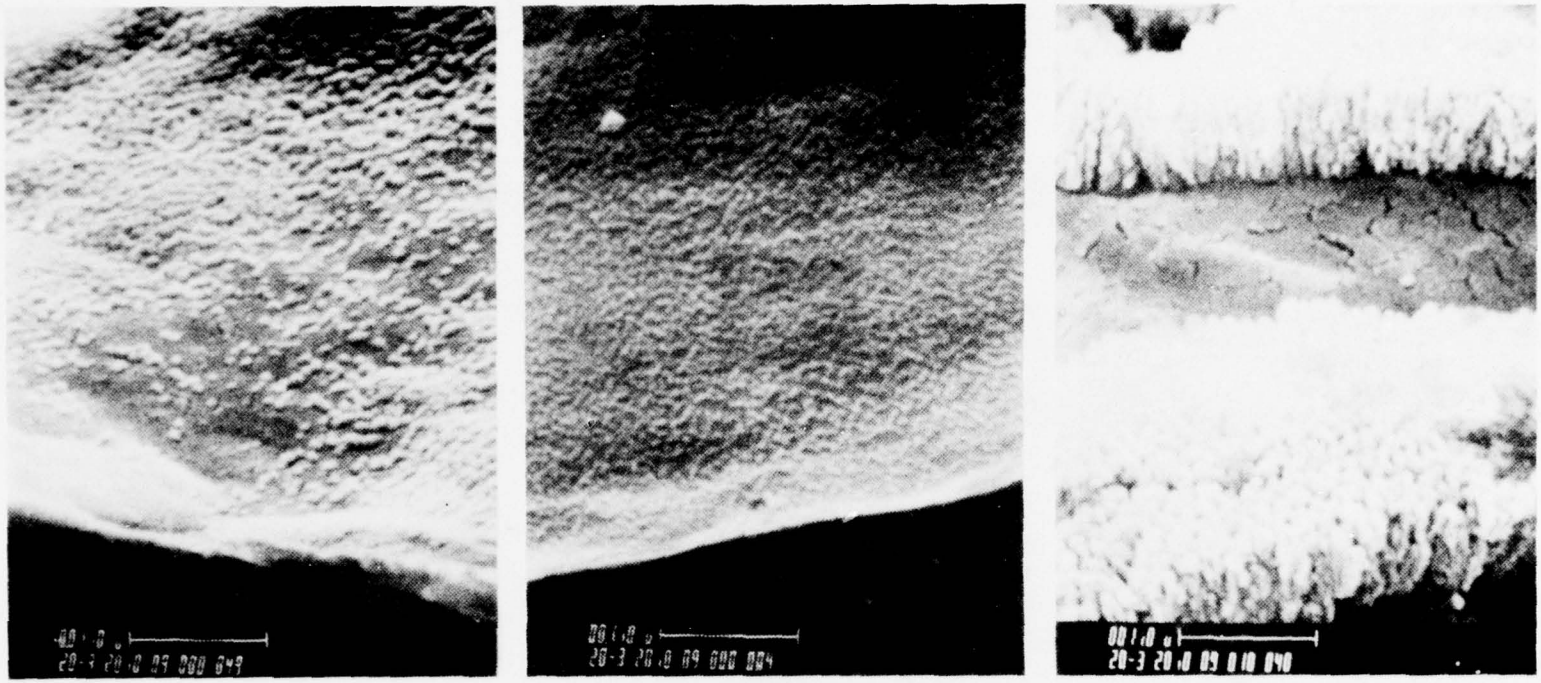
A mat adhesive and autoclave cure were used for the FPL and PABST system panels, and a paste adhesive and oven cure were used for the weldbond panels. With the paste adhesive, a 0.003-inch thick aluminum shim, Figure 2, extending 3/8-inch in from the sides of the 6-inch x 6-inch weldbond panels, was used to maintain a minimum bondline thickness of 0.005 inch. Ten pounds of lead weights were placed on each weldbond panel during the cure cycle to obtain a uniform bondline thickness.

Lots E and F of the paste adhesive A1444B (Reference 4), were used to prepare all the weldbond specimens. However, the wedge crack growth after only one month exposure at the sea coast was greater than 0.5 inch for three of the material combinations. An investigation was conducted which revealed that the adhesive for the weldbond test panels was undercured. Therefore, a second set of weldbond wedge panels was prepared using Lot J, A1444B. This delayed the initial exposure at the sea coast by two months for the weldbond specimens.

## RESULTS AND DISCUSSION

### Wedge Tests – Sea Coast

The average wedge crack growth for the sea coast exposure is presented in Figures 6, 7, 8, and 9 for the three bonding systems and the four material combinations. For all four material combinations, the wedge crack-growth rate was higher for the weldbond system than for the FPL bonding system and the PABST bonding system. However, the FPL system had a crack-growth rate very similar to the weldbond system with a delay time of only approximately one month to reach the same crack growth as the weldbond system. Therefore, although the relative ranking of durability shows the FPL system to be better than the weldbond system, from a practical point of view the two systems have essentially the same durability for a sea coast exposure with a crack-growth greater than 1 inch in three or four months for three of the four material combinations, and approximately 0.8-inch crack growth for 2024-T3 bare bonded to 2024-T3 bare after 10 months exposure. In contrast, the PABST bonding system showed essentially no crack growth (less than 0.04 inch) after a 12 month sea coast exposure



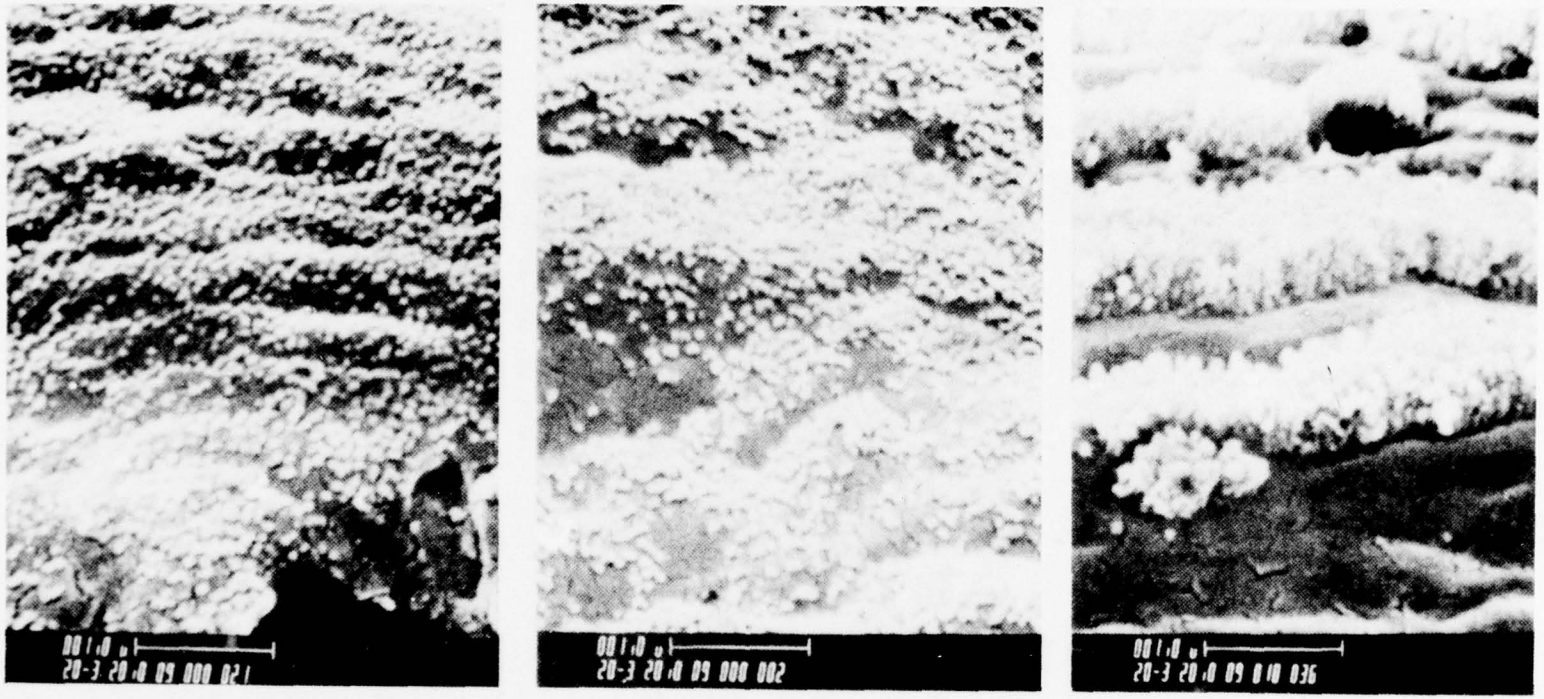
FPL SURFACE TREATMENT

WELDBOND SURFACE TREATMENT

PABST SURFACE TREATMENT

**MAGNIFICATION 20,000X**

**FIGURE 3. TYPICAL ANODIZED LAYER ON 2024-T3 ALCLAD**



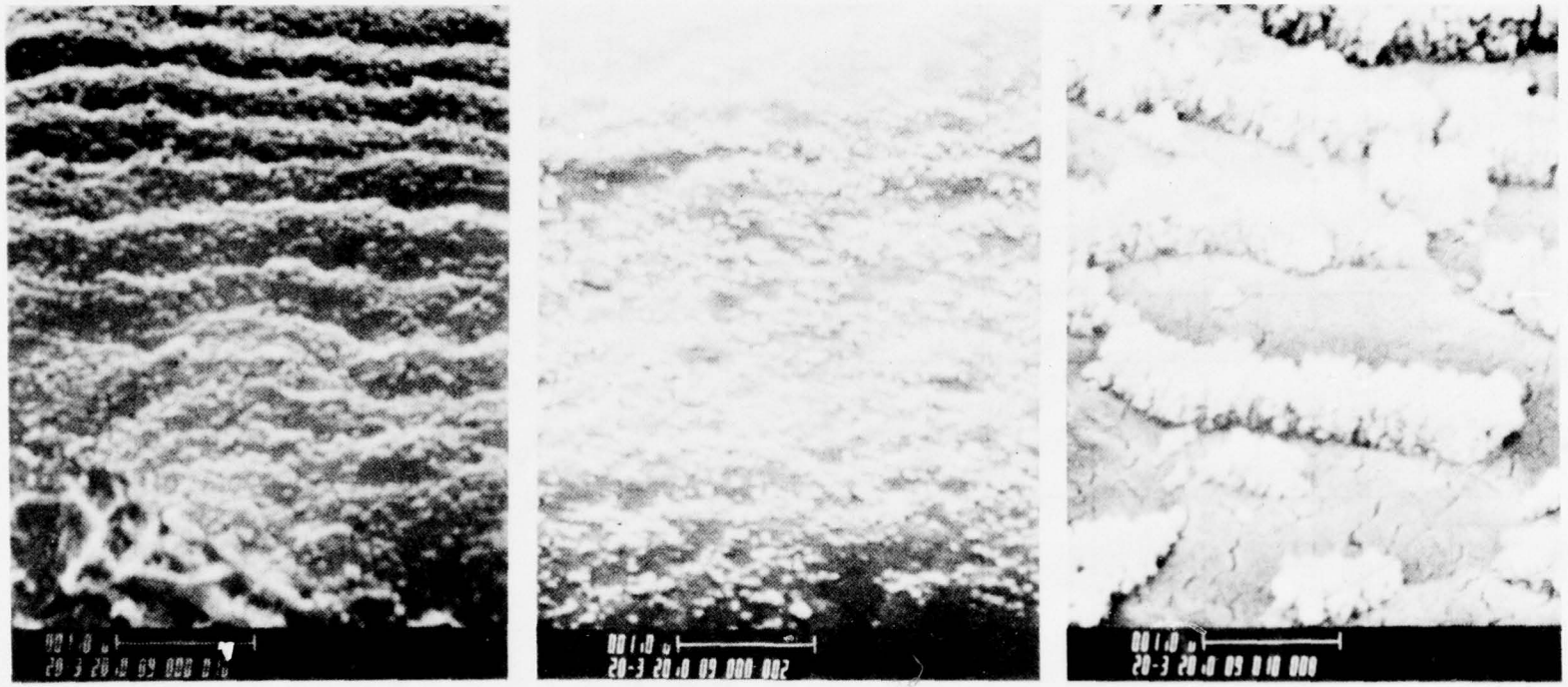
FPL SURFACE TREATMENT

WELDBOND SURFACE TREATMENT

PABST SURFACE TREATMENT

**MAGNIFICATION 20,000X**

**FIGURE 4. TYPICAL ANODIZED LAYER ON 2024-T3 BARE**



FPL SURFACE TREATMENT | WELDBOND SURFACE TREATMENT | PABST SURFACE TREATMENT

**MAGNIFICATION 20,000X**

**FIGURE 5. TYPICAL ANODIZED LAYER ON 7075-T6 BARE**

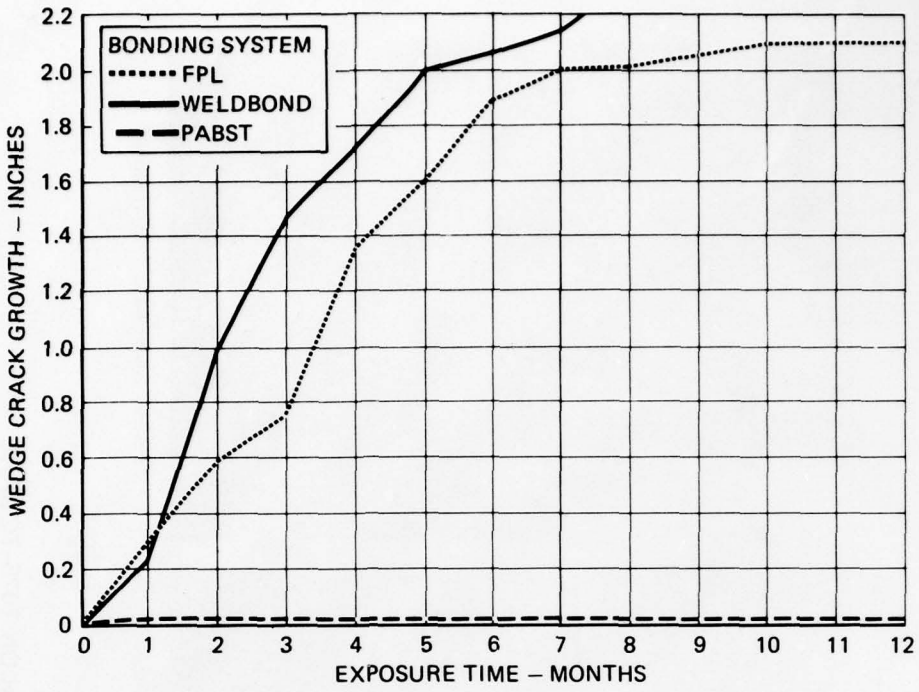



**FIGURE 6. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 ALCLAD/7075-T6 BARE – SEA COAST EXPOSURE**

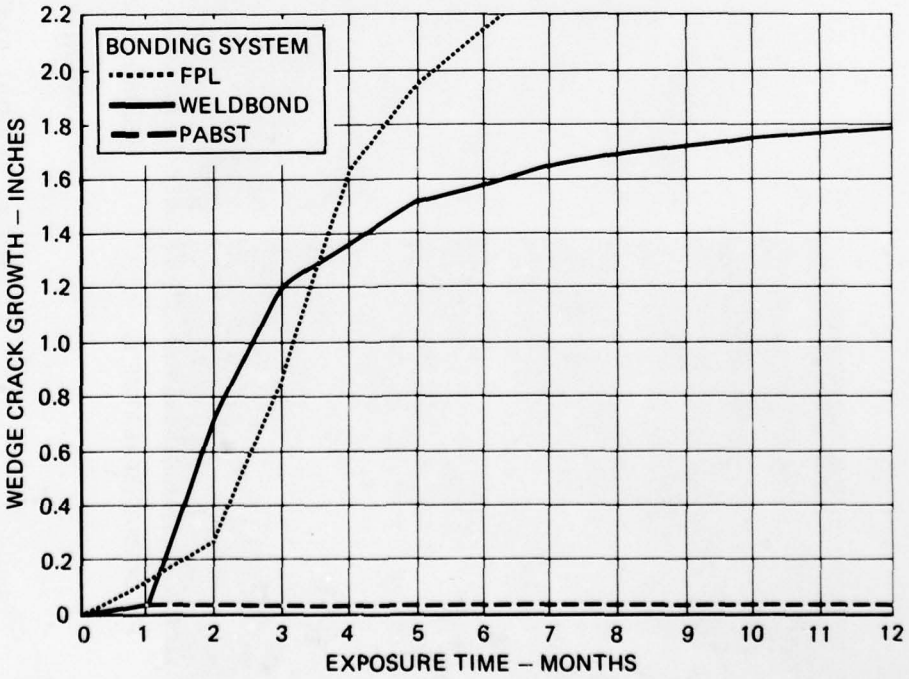



**FIGURE 7. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 BARE/7075-T6 BARE – SEA COAST EXPOSURE**

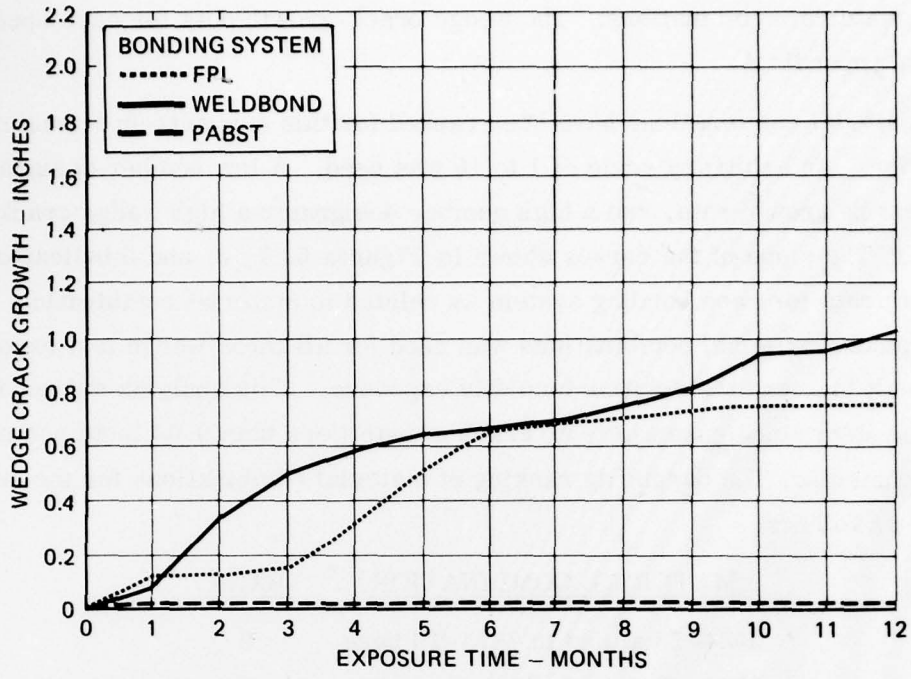



**FIGURE 8. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 BARE/2024-T3 BARE – SEA COAST EXPOSURE**

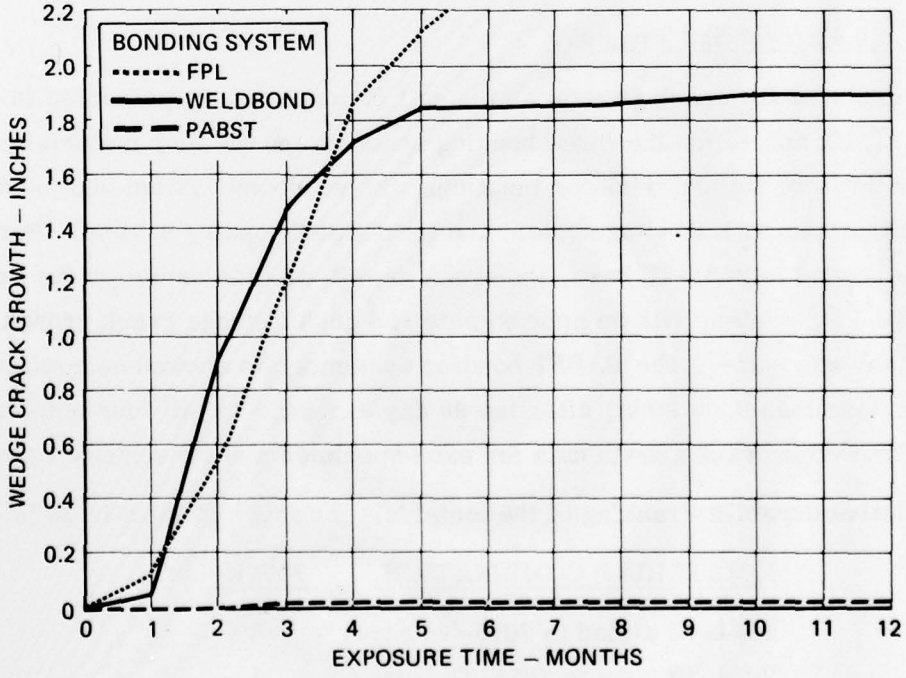



**FIGURE 9. AVERAGE WEDGE CRACK GROWTH OF 7075-T6 BARE/7075-T6 BARE – SEA COAST EXPOSURE**

for all four material combinations. The wedge crack-growth data for each specimen are presented in Appendix A.

The material combinations have been ranked for this exposure in terms of durability behavior. An arbitrary scale of 1 to 10 was used. A low number designates a low wedge crack-growth rate, and a high number designates a high wedge crack-growth rate. The slope of the curves shown in Figures 6, 7, 8, and 9 indicates the wedge crack-growth rate for each bonding system as related to material combination. This method of ranking material combinations was used for all three wedge test exposures, sea coast, salt fog, and the relative humidity exposure. This analysis did not include the PABST system since essentially no crack growth (less than 0.04 inch) occurred for these environments. The durability ranking of material combinations for the sea coast exposure is as follows:

| MATERIAL COMBINATION | RANK |
|---|---|
| 2024-T3 alclad to 7075-T6 bare | 9 |
| 2024-T3 bare to 7075-T6 bare | 8 |
| 2024-T3 bare to 2024-T3 bare | 3 |
| 7075-T6 bare to 7075-T6 bare | 10 |

Wedge Tests – 5 Percent Salt Fog, 95F

The average wedge crack growth for the salt fog exposure is presented in Figures 10, 11, 12, and 13 for the three bonding systems and the four material combinations. For three of the material combinations, the weldbond system showed a faster crack growth than the FPL bonding system and the PABST bonding system. For 2024-T3 bare bonded to 2024-T3 bare, the crack growth was the same for the weldbond system and the FPL system with an approximate 0.5-inch average crack growth at the end of the 90 day exposure. The PABST bonding system again showed essentially no crack growth (less than 0.03 inch), after the 90 day exposure for all four material combinations. The wedge crack growth data for each specimen are presented in Appendix A.

The relative durability ranking of the materials for this exposure is as follows:

| MATERIAL COMBINATION | RANK |
|---|---|
| 2024-T3 alclad to 7075-T6 bare | 8 |
| 2024-T3 bare to 7075-T6 bare | 5 |
| 2024-T3 bare to 2024-T3 bare | 3 |
| 7075-T6 bare to 7075-T6 bare | 4 |

A question arose as to which environment is more severe, the sea coast beach site or the salt fog exposure. An analysis of the wedge test data shows that the answer depends upon the bonding system, the material combination, and the exposure time. The severity of the sea coast exposure as compared to the severity of the salt fog exposure for a 90 day (or 3 month) time period is as follows:

| BONDING SYSTEM | MATERIAL COMBINATION | MORE SEVERE |
|---|---|---|
| FPL | 2024-T3 alclad/7075-T6 bare | Sea Coast |
| | 2024-T3 bare/7075-T6 bare | Sea Coast |
| | 2024-T3 bare/2024-T3 bare | Salt Fog |
| | 7075-T6 bare/7075-T6 bare | Sea Coast |
| Weldbond | 2024-T3 alclad/7075-T6 bare | Salt Fog |
| | 2024-T3 bare/7075-T6 bare | Same |
| | 2024-T3 bare/2024-T3 bare | Same |
| | 7075-T6 bare/7075-T6 bare | Sea Coast |

It can be seen from this analysis that the severity question is not easily answered. For the weldbond system, two material combinations showed the same wedge crack growth for both environments, one material combination showed less crack growth at the sea coast, and one material combination showed greater crack growth. However, for the FPL bonding system, three of the four material combinations showed greater crack-growth for the 90-day sea coast exposure than the 90-day salt fog exposure.

Although there is not a clear correlation between the sea coast and the salt fog exposure, the 90-day salt fog test is more easily reproduced and is more available to most companies, as an alternate to the sea coast exposure.

Wedge Tests – 95 to 100 Percent Relative Humidity, 120F

The average wedge crack growth for the 95 to 100 percent relative humidity exposure is shown in Figures 14, 15, 16, and 17 for the three bonding systems and the four material combinations. For all three bonding systems, the average wedge crack growth was less than 0.2 inch for the 60-day exposure and less than 0.4 inch for the 90-day exposure. Therefore, it is difficult to rank the three bonding systems or the

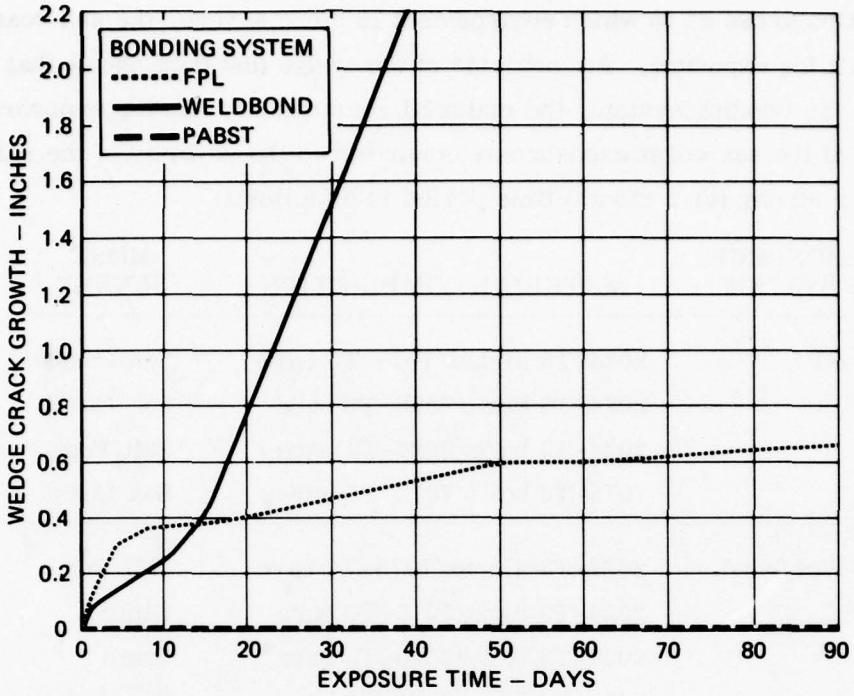



**FIGURE 10. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 ALCLAD/7075-T6 BARE – SALT FOG EXPOSURE**

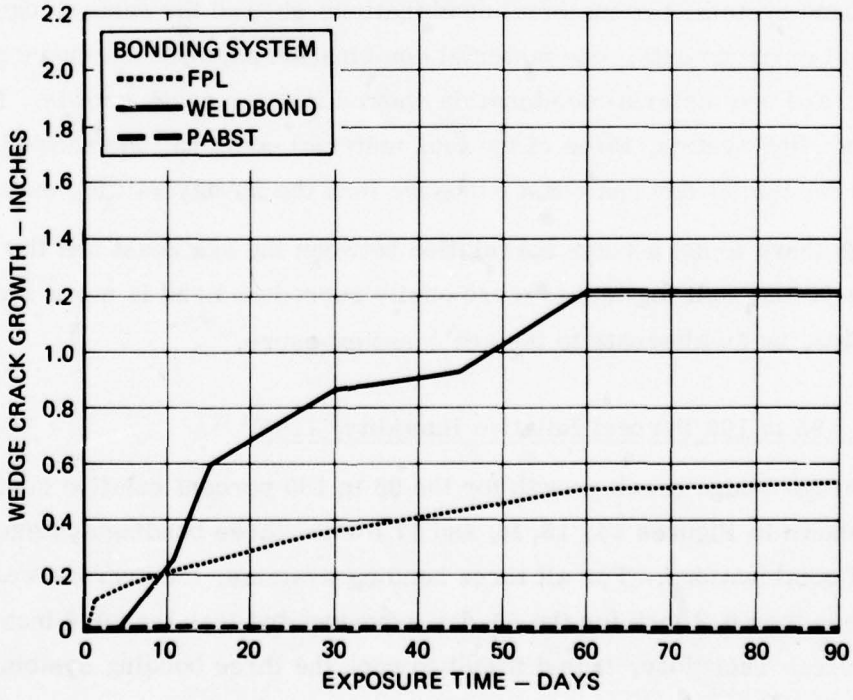



**FIGURE 11. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 BARE/7075-T6 BARE – SALT FOG EXPOSURE**

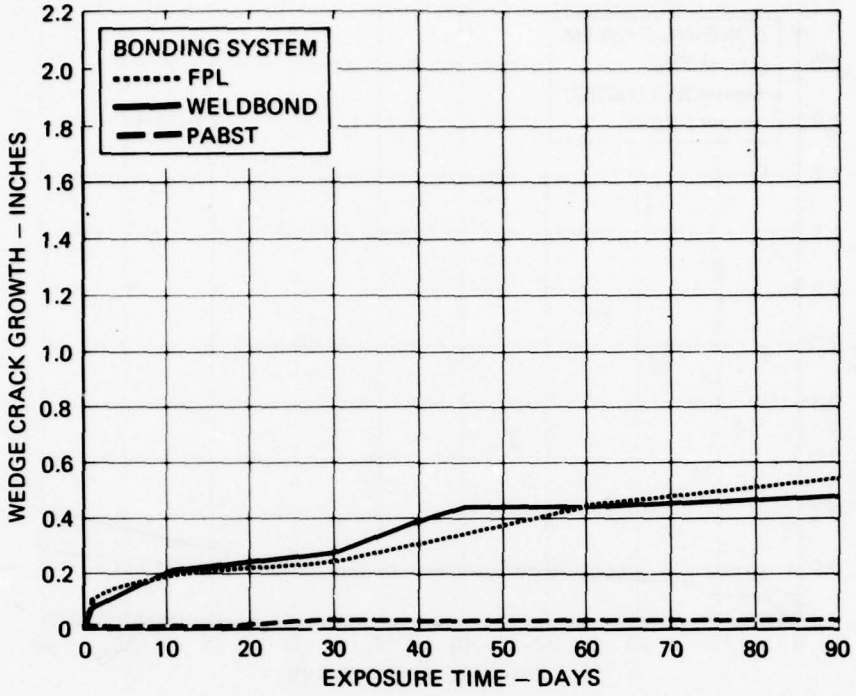



**FIGURE 12. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 BARE/2024-T3 BARE – SALT FOG EXPOSURE**

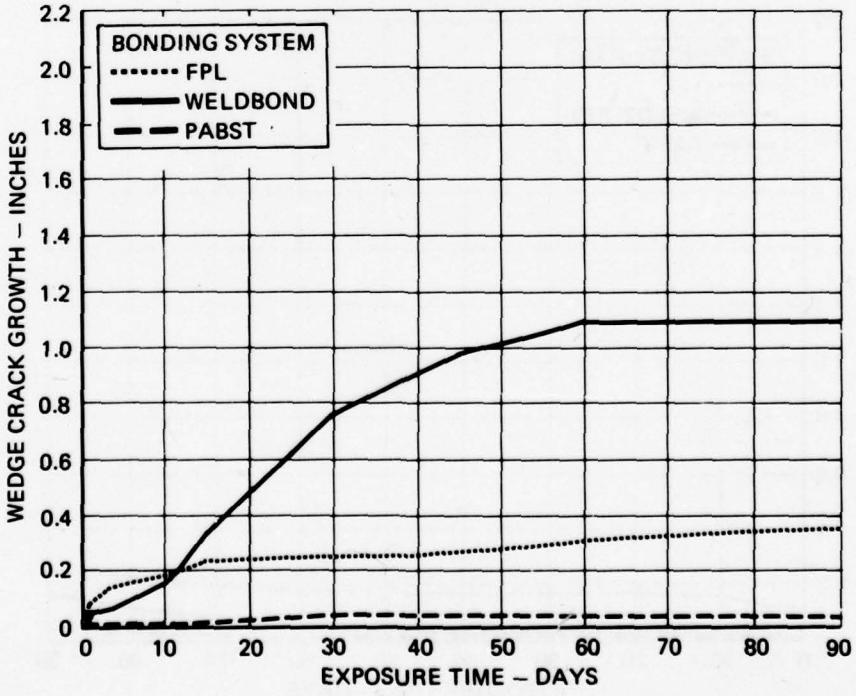



**FIGURE 13. AVERAGE WEDGE CRACK GROWTH OF 7075-T6 BARE/7075-T6 BARE – SALT FOG EXPOSURE**

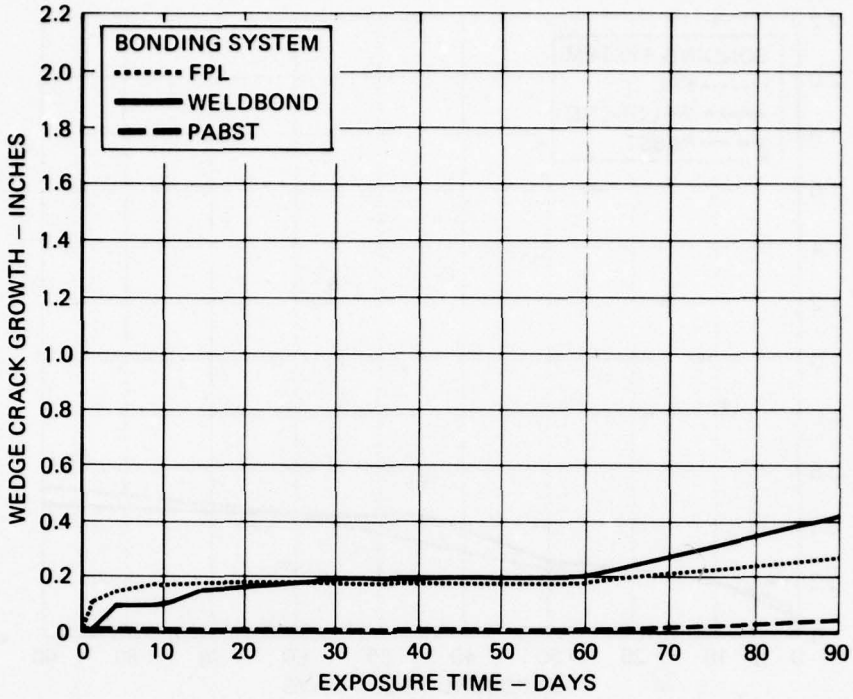



**FIGURE 14. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 ALCLAD/7075-T6 BARE – 95-100 PERCENT RELATIVE HUMIDITY**

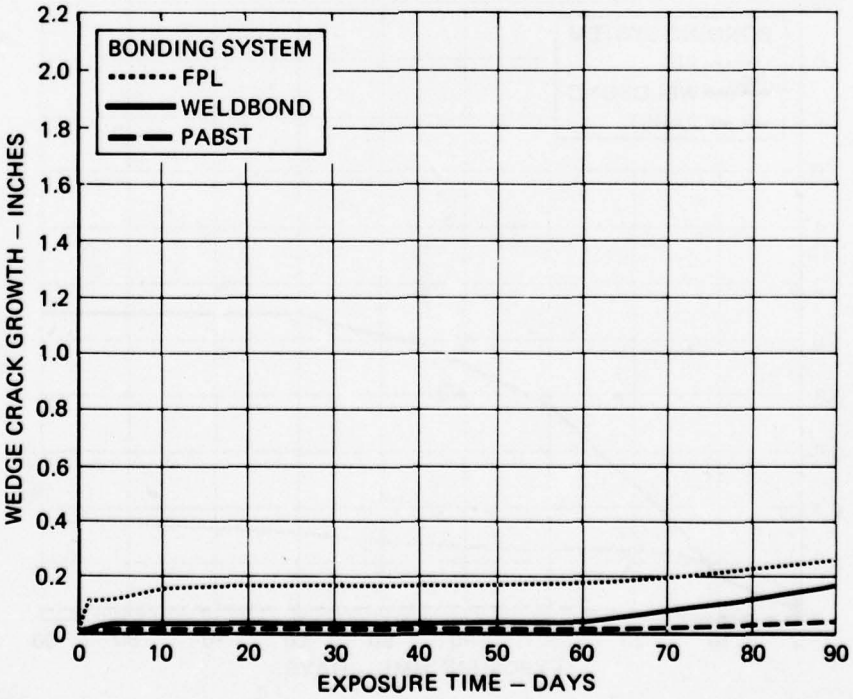



**FIGURE 15. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 BARE/7075-T6 BARE – 95-100 PERCENT RELATIVE HUMIDITY**

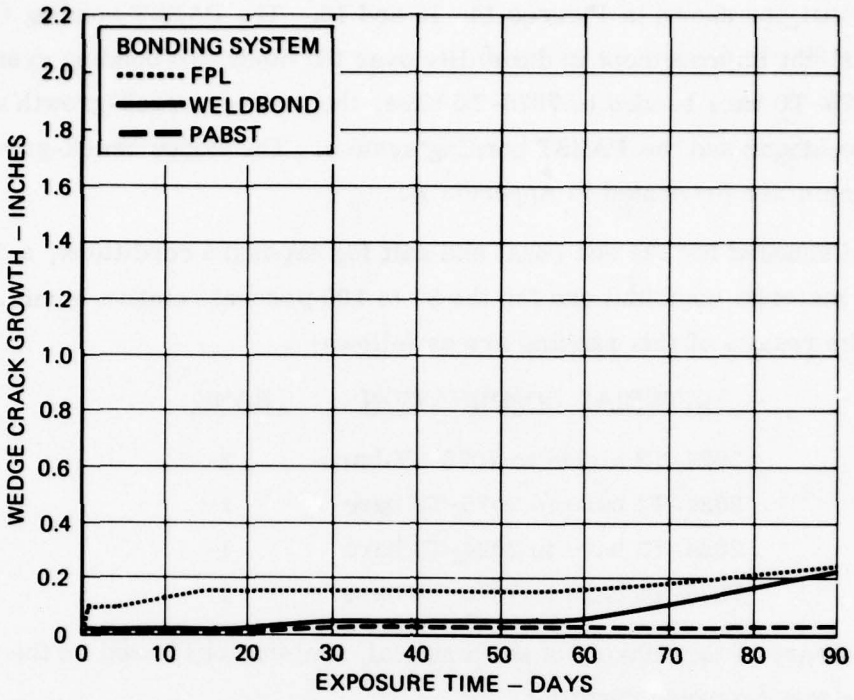



**FIGURE 16. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 BARE/2024-T3 BARE – 95-100 PERCENT RELATIVE HUMIDITY**

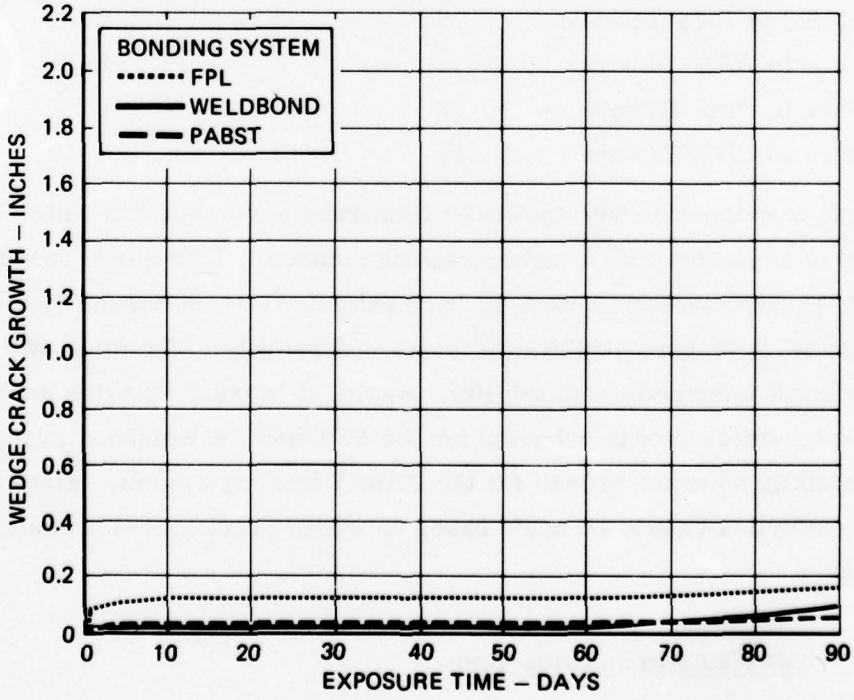



**FIGURE 17. AVERAGE WEDGE CRACK GROWTH OF 7075-T6 BARE/7075-T6 BARE – 95-100 PERCENT RELATIVE HUMIDITY**

material combinations shown in Figures 14, 15 and 16. The PABST bonding system had only very slight improvement in durability over the other two bonding systems. In fact, for 7075-T6 bare bonded to 7075-T6 bare, the average crack-growth was equal for the weldbond and the PABST bonding system. The wedge crack-growth data for each specimen are presented in Appendix A.

As was discussed for the sea coast and salt fog exposure conditions, a durability ranking of the material combinations for the 95 to 100 percent relative humidity exposure was made. The results of this ranking are as follows:

| MATERIAL COMBINATION | RANK |
|---|---|
| 2024-T3 alclad to 7075-T6 bare | 2 |
| 2024-T3 bare to 7075-T6 bare | 1 |
| 2024-T3 bare to 2024-T3 bare | 1 |
| 7075-T6 bare to 7075-T6 bare | 1 |

An overall summary of the ranking of the material combinations based on the three different wedge test exposure conditions is:

| Material Combination | Sea Coast | Salt Fog | Relative Humidity | Total |
|---|---|---|---|---|
| 2024-T3 alclad to 7075-T6 bare | 9 | 8 | 2 | 19 |
| 2024-T3 bare to 7075-T6 bare | 8 | 5 | 1 | 14 |
| 2024-T3 bare to 2024-T3 bare | 3 | 3 | 1 | 7 |
| 7075-T6 bare to 7075-T6 bare | 10 | 4 | 1 | 15 |

The material combination with the lower total ranking number has better durability than a material combination with a higher ranking number. Therefore, based on this analysis, 2024-T3 bare bonded to 2024-T3 bare exhibits the best durability and 2024-T3 alclad bonded to 7075-T6 bare exhibits the poorest durability. The other two material combinations exhibit intermediate durability. Again, it is noted that this analysis is based on the wedge crack growth behavior for the FPL and the weldbond systems. Since there was essentially no crack growth for the PABST bonding system, relative durability ranking of the materials cannot be made based on wedge crack-growth results for the PABST system.

Constant Load – Salt Water Immersion Tests

The results for the constant load-salt water immersion tests are shown in Tables 5, 6, and 7 for both the 1,000 hour and the 2,000-hour immersion in the 3.5

percent salt water under a constant load. The residual strength for the specimens tested after this exposure was greater than 96 percent of the control test strength values for all three bonding systems and all four material combinations except for one value of 94 percent obtained for the weldbond system for 7075-T6 bare weldbonded to 7075-T6 bare, under high load (1,000 hour) conditions. This average loss of 6 percent of the ultimate lap-shear strength is not considered significant, but for the purposes of this program the weldbond system was assigned a higher durability ranking number (poorer durability) than the other bonding systems. Also, the weldbond system had an unexplained premature failure after 615 hours for the 1,000 hour, 2024-T3/2024-T3 test series, which again earned this system a poorer durability ranking.

The lap-shear area was examined for corrosion attack after the residual strength tests were conducted. No evidence of corrosion attack was found for any of the lap-shear test specimens. Since there was no evidence of corrosion attack at the lap-joint interface and since there was no significant loss in residual lap-shear strength, the relative durability ranking of the material combinations cannot be made for this test series.

Surface Scratch Test

The results for the surface scratch tests are shown in Table 8, for the three bonding surface treatments and three materials. The objective of this test was to determine if the surface treatment used for each of the three joining systems would pass the 2,000 hour salt fog exposure if a scratch were made through the standard coating of MIL-P-23377 epoxy polyamide primer and MIL-C-81773 polyurethane top coat. All three surface treatments when coated with the standard primer and top coat passed the 2,000 hour exposure to the 5 percent salt fog at 95F. No evidence of surface corrosion or corrosion at the scratch was found on these panels. Therefore, all three surface treatments and three materials were rated equal for this series of surface corrosion tests.

In addition to the coated panels, uncoated panels were also exposed for 2,000 hours. The results of this exposure for uncoated panels is also shown in Table 8. As expected, panels prepared by the PABST method showed no evidence of corrosion; panels prepared by the FPL method showed slight corrosion; and panels prepared by the weldbond method showed moderate to severe corrosion. As seen in Figure 1, the PABST surface treatment prior to adhesive application produces an aluminum surface with a thick oxide layer on which a protective primer, BR-127, is applied. The FPL

## TABLE 5. CONSTANT LOAD/SALT WATER IMMERSION TEST RESULTS FOR THE FPL SYSTEM

| | 2024-T3 CLAD TO 7075-T6 BARE | 2024-T3 BARE TO 7075-T6 BARE | 2024-T3 BARE TO 2024-T3 BARE | 7075-T6 BARE TO 7075-T6 BARE |
|---|---|---|---|---|
| CONTROL STRENGTH (LBS) | A11 3650<br>A12 3700<br>A7 3650<br>A8 3700 | B11 3700<br>B12 3650<br>B7 3750<br>B8 3700 | C11 3850<br>C12 3800<br>C7 3750<br>C8 3800 | D11 5150<br>D12 4950<br>D7 5100<br>D8 5150 |
| AVERAGE | 3675 | 3700 | 3800 | 5088 |
| 1000 HOUR DATA: LOAD (LBS) | 2380 | 2380 | 2380 | 3000 |
| RESIDUAL STRENGTH (LBS) | A1 3850<br>A2 3850<br>A3 3700 | B1 3650<br>B2 3800<br>B3 3750 | C2 3700<br>C3 3800<br>C4 3750 | D1 4800<br>D2 5000<br>D3 5050 |
| AVERAGE | 3800 | 3730 | 3750 | 4950 |
| PERCENT LOSS | NONE | NONE | 1.3% | 2.7% |
| 2000 HOUR DATA: LOAD (LBS) | 1875 | 1875 | 1875 | 2380 |
| RESIDUAL STRENGTH (LBS) | A4 3650<br>A5 3700<br>A6 3650 | B4 3700<br>B5 3700<br>B6 3650 | C1 3600<br>C5 3650<br>C6 3700 | D4 5100<br>D5 4850<br>D6 4950 |
| AVERAGE | 3665 | 3680 | 3650 | 4970 |
| PERCENT LOSS | NONE | NONE | 3.9% | 2.3% |
| FAILURE MODE | 100% COHESIVE | 100% COHESIVE | 100% COHESIVE | 100% COHESIVE |

## TABLE 6. CONSTANT LOAD/SALT WATER IMMERSION TEST RESULTS FOR THE WELDBOND SYSTEM

| | 2024-T3 CLAD TO 7075-T6 BARE | 2024-T3 BARE TO 7075-T6 BARE | 2024-T3 BARE TO 2024-T3 BARE | 7075-T6 BARE TO 7075-T6 BARE |
|---|---|---|---|---|
| CONTROL STRENGTH (LBS) | E9 4000<br>E3 4000<br>E7 4000 | F5 3900<br>F8 3800<br>F1 4000<br>F3 3900 | G1 3800<br>G9 3750<br>G8 3900<br>G10 3800 | H1 5200<br>H9 5150<br>H2 5200<br>H10 5200 |
| AVERAGE | 4000 | 3900 | 3815 | 5190 |
| 1000 HOUR DATA: LOAD (LBS) | 2380 | 2380 | 2380 | 3000 |
| RESIDUAL STRENGTH (LBS) | E4 3700<br>E5 3900<br>E6 4100 | F7 3850<br>F8 3800<br>F10 3900 | G5 3750<br>G6 3800<br>G7 (1) | H6 4800<br>H7 4700<br>H8 5000 |
| AVERAGE | 3900 | 3850 | 3775 | 4830 |
| PERCENT LOSS | 2.5% | 1.3% | 1.0% | 5.9% |
| 2000 HOUR DATA: LOAD (LBS) | 1875 | 1875 | 1875 | 2380 |
| RESIDUAL STRENGTH (LBS) | E1 3900<br>E2 4100<br>E8 4150 | F2 3900<br>F4 3850<br>F6 3900 | G2 4050<br>G3 3900<br>G4 3550 | H3 5100<br>H4 5050<br>H5 5000 |
| AVERAGE | 4050 | 3880 | 3830 | 5050 |
| PERCENT LOSS | NONE | 0.5% | NONE | 2.7% |
| FAILURE MODE | 60 TO 70% COHESIVE | 60 TO 80% COHESIVE | 60 TO 90% COHESIVE | 80 TO 95% COHESIVE |

(1) FAILED IN 615 HOURS Not included in average.

## TABLE 7. CONSTANT LOAD/SALT WATER IMMERSION TEST RESULTS FOR THE PABST SYSTEM

| | 2024-T3 CLAD TO 7075-T6 BARE | 2024-T3 BARE TO 7075-T6 BARE | 2024-T3 BARE TO 2024-T3 BARE | 7075-T6 BARE TO 7075-T6 BARE |
|---|---|---|---|---|
| CONTROL STRENGTH (LBS) | I11 4150<br>I12 3750<br>I7 4000<br>I8 3950 | J1 3950<br>J10 4000<br>J8 3950<br>J9 4000 | K1 3700<br>K11 3750<br>K8 3850<br>K9 3850 | L10 5200<br>L11 5250<br>L7 5100<br>L8 5150 |
| AVERAGE | 3962 | 3975 | 3787 | 5175 |
| 1000 HOUR DATA: LOAD (LBS) | 2380 | 2380 | 2380 | 3000 |
| RESIDUAL STRENGTH (LBS) | I1 4100<br>I2 4050<br>I3 4000 | J5 4050<br>J6 4050<br>J7 4050 | K5 3950<br>K6 3850<br>K7 3950 | L1 5200<br>L2 5200<br>L3 5100 |
| AVERAGE | 4050 | 4050 | 3915 | 5165 |
| PERCENT LOSS | NONE | NONE | NONE | NONE |
| 2000 HOUR DATA: LOAD (LBS) | 1875 | 1875 | 1875 | 2380 |
| RESIDUAL STRENGTH (LBS) | I4 3900<br>I5 4000<br>I6 4100 | J2 4000<br>J3 4050<br>J4 4050 | K2 3850<br>K3 3900<br>K4 3850 | L4 5050<br>L5 5100<br>L6 5000 |
| AVERAGE | 4000 | 4035 | 3865 | 5050 |
| PERCENT LOSS | NONE | NONE | NONE | 2.4% |
| FAILURE MODE | 100% COHESIVE | 100% COHESIVE | 100% COHESIVE | 100% COHESIVE |

## TABLE 8. SURFACE SCRATCH TEST RESULTS

EXPOSURE: 5 PERCENT SALT FOG AT 95F, ASTM B 117

CORROSION RESULT CODE: O – NO CHANGE
S – SLIGHT CORROSION
M – MODERATE CORROSION
X – SEVERE CORROSION

| JOINING SYSTEM | MATERIAL | CORROSION RESULTS FOR EXPOSURE (HOURS) | | | | |
|---|---|---|---|---|---|---|
| | | 72 | 500 | 1000 | 1500 | 2000 |
| FPL | 2024-T3 ALCLAD – COATED* | O | O | O | O | O |
| | – UNCOATED | O | O | O | S | S |
| | 2024-T3 BARE – COATED* | O | O | O | O | O |
| | – UNCOATED | O | O | O | O | S |
| | 7075-T6 BARE – COATED* | O | O | O | O | O |
| | – UNCOATED | O | O | S | S | S |
| WELDBOND | 2024-T3 ALCLAD – COATED* | O | O | O | O | O |
| | – UNCOATED | S | S | M | M | M |
| | 2024-T3 BARE – COATED* | O | O | O | O | O |
| | – UNCOATED | X | X | X | X | X |
| | 7075-T6 BARE – COATED* | O | O | O | O | O |
| | – UNCOATED | X | X | X | X | X |
| PABST | 2024-T3 ALCLAD – COATED* | O | O | O | O | O |
| | – UNCOATED | O | O | O | O | O |
| | 2024-T3 BARE – COATED* | O | O | O | O | O |
| | – UNCOATED | O | O | O | O | O |
| | 7075-T6 BARE – COATED* | O | O | O | O | O |
| | – UNCOATED | O | O | O | O | O |
| ALODINE CONTROL PANELS | 2024-T3 ALCLAD | O | O | O | O | O |
| | 2024-T3 BARE | O | O | O | O | O |
| | 7075-T6 BARE | O | O | O | O | O |

*COATED SPECIMENS WERE PRIMED WITH MIL-P-23377 EPOXY POLYAMIDE PRIMER AND TOP COATED WITH MIL-C-81773 POLYURETHANE PAINT

surface treatment produces a thin oxide layer but also includes a layer of protective primer, BR-127. On the other hand, the weldbond surface preparation was developed with a thin oxide layer and no protective primer so that resistance spot welds could easily be made. The intent of the weldbond surface preparation was to enable resistance spot welds to be made and to allow the durable paste adhesive, A1444B, to seal and protect the weldbond interface. The weldbond surface preparation alone will not provide sufficient corrosion protection for exterior aluminum surfaces. However, if the surface is primed or primed and painted, it can be expected to perform similar to the PABST and FPL panels.

Durability Ranking of Three Joining Systems

An analysis was made of all the durability tests conducted for the two adhesive bonding systems and the weldbond system. A summary of this analysis is presented in Table 9. The joining system which had the best durability for a specific test series and material combination was ranked as number 1, the second best was ranked as number 2, and the third best was ranked as number 3. The ranking numbers were totaled for each joining system. Therefore, the system having the lowest sum total had the best durability for the tests conducted for this program. The final ranking of the three joining systems in terms of decreasing durability is: PABST, FPL and weldbonding. As discussed in the results section for the surface scratch tests, this ranking is not surprising since both the PABST and FPL surface treatments prior to adhesive bonding include the addition of a protective coat of primer, BR-127, and the PABST system has the added advantage of a thick oxide layer.

Based on the results of the constant load-salt water immersion tests, the durability of the three joining systems is equal. Therefore, the durability ranking noted above was based on the results of the wedge tests. However, it is difficult to correlate the stress that is created in a wedge-test specimen to the stress that would occur in actual aircraft panels. Also, the wedge test does not evaluate completely the durability of the weldbond system since spot welding, which is an integral part of the weldbond joining system, is not used in the preparation of the standard wedge-test specimen. In order to have commonality for the wedge-test comparisons, the wedge-test specimens for the weldbond system were not welded. Data for wedge specimens which were welded are presented in the next section of this report. In summary, the wedge test provided a good method for evaluating the durability of adhesive bonding systems but not necessarily that of the complete weldbond system.

## TABLE 9. DURABILITY RANKING OF THREE JOINING SYSTEMS

| TYPE OF TEST | EXPOSURE CONDITIONS | MATERIAL (1) | FPL ETCH | WELDBOND | PABST |
|---|---|---|---|---|---|
| WEDGE | 95-100% RELATIVE HUMIDITY AT 120F FOR 90 DAYS | 24C-75B | 2 | 2 | 1 |
| | | 24B-75B | 2 | 2 | 1 |
| | | 24B-24B | 2 | 2 | 1 |
| | | 75B-75B | 2 | 1 | 1 |
| WEDGE | 5% SALT FOG AT 95F FOR 90 DAYS | 24C-75B | 2 | 3 | 1 |
| | | 24B-75B | 2 | 3 | 1 |
| | | 24B-24B | 2 | 2 | 1 |
| | | 75B-75B | 2 | 3 | 1 |
| WEDGE | SEA COAST, EL SEGUNDO, CALIF FOR 12 MONTHS | 24C-75B | 2 | 3 | 1 |
| | | 24B-75B | 2 | 3 | 1 |
| | | 24B-24B | 2 | 3 | 1 |
| | | 75B-75B | 2 | 3 | 1 |
| CONSTANT LOAD SALT WATER IMMERSION | 3.5% SALT WATER EXPOSURE FOR 2000 HOURS | 24C-75B | 1 | 1 | 1 |
| | | 24B-75B | 1 | 1 | 1 |
| | | 24B-24B | 1 | 1 | 1 |
| | | 75B-75B | 1 | 1 | 1 |
| CONSTANT LOAD SALT WATER IMMERSION | 3.5% SALT WATER EXPOSURE FOR 1000 HOURS | 24C-75B | 1 | 1 | 1 |
| | | 24B-75B | 1 | 1 | 1 |
| | | 24B-24B | 1 | 2 | 1 |
| | | 75B-75B | 1 | 2 | 1 |
| SURFACE SCRATCH PANEL (2) | 5% SALT FOG AT 95F FOR 2000 HOURS | ALL | 1 | 1 | 1 |
| | TOTAL | | 33 | 41 | 21 |

(1) 24C = 2024-T3 alclad; 24B = 2024-T3 bare; 75B = 7075-T6 bare.

(2) These surface scratch panels were primed with MIL-P-23377 epoxy polyamide primer and top coated with MIL-C-81773 polyurethane paint. This test is used to indicate surface corrosion behavior of the materials used in the three joining systems.

## WELDBOND DURABILITY IMPROVEMENT STUDY (An Independent Northrop Program)

The object of the addendum to the weldbond program was to compare the durability of the FPL and PABST adhesive bonding system with that of the weldbond system. Concurrent with this effort, a separate Northrop IRAD program was conducted to determine if a spray coat of BR-127 primer on the weldbond surface would improve the durability of this joining method and still result in a surface that could be spot welded using the standard weld parameters that had been established during the weldbond program.

This separate effort was conducted in three phases. The first phase was to establish what thickness of BR-127 primer could be welded in the uncured state using standard weldbond weld parameters. The second phase was to determine if this weldable layer of BR-127 did improve the durability of the weldbond system. If the durability were improved, then a third phase was planned to show the effects of the BR-127 on the weldbond properties. A test matrix for the last two phases is shown in Table 10.

The material combination, 2024-T3 alclad bonded to 7075-T6, was selected for the durability evaluation since this combination was more susceptible to wedge crack growth than the other three material combinations tested during the weldbond addendum program. Wedge tests were conducted for two different exposures: 95F salt fog and the sea coast. Lap-shear tests were conducted at room temperature and -65F using 7075-T6 weldbonded to 7075-T6. High-load transfer fatigue tests and T-peel tests were also conducted using 7075-T6.

### Weldability Evaluation

The first phase, weldability evaluation, revealed that resistance spot welds could easily be made through BR-127 primer if the primer thickness was 0.00004 inch, and the primer was air dried, not fully cured. Welds made on panels with a primer thickness of 0.00008 inch were inconsistent in quality, and panels with a primer thickness of 0.00015 inch could not be welded using the standard weldbond weld parameters. The standard thickness for BR-127 primer is 0.00015 to 0.00030 inch. Based on the results of the weldability study, the test specimens for this investigation were prepared using a very thin, 0.00004-inch coat of BR-127 primer. The aluminum sheet was cleaned and anodized according to the standard weldbond procedures. Then the primer was applied as a 1/2 box spray coat to match the color tone of prior samples of known primer thickness. Quality control panels were sprayed at the same time as the test panels. The thickness of the primer on these control panels after curing was found to be

0.00004 inch. Primer thickness was measured using a Fischer Permascope (eddy current system) which has an accuracy of 0.00003 inch (2 percent full scale). The primer was allowed to air dry for a minimum of 30 minutes before applying the adhesive. Paste adhesive A1444B, Lot K, was used for these test panels. The primer was co-cured with the adhesive at 250-260F for 2 hours.

## Wedge Test Durability Results

The second phase, durability evaluation, revealed that a very thin (0.00004-inch) layer of BR-127 primer, co-cured with the adhesive, was sufficient to improve the durability of the weldbond system to the extent that it almost equals the durability of the PABST adhesive bonding system. The durability of the weldbond system with the BR-127 primer exposed to 95F salt fog shows an average wedge crack growth of less than 0.20 inch in 90 days compared to more than 1.0-inch crack growth in less than 25 days for the weldbond system without the BR-127 primer, Figure 18. These wedge tests for the weldbond/BR-127 system, still in progress, show an average wedge crack growth of less than 0.20 inch even after 214 days (7 months). Also the durability of the weldbond/BR-127 system is much better than the FPL adhesive system.

The results of the sea coast wedge tests are shown in Figure 19. For this exposure condition, the durability of the weldbond/BR-127 system is essentially equal to the durability of the PABST system after 5 months exposure, i.e., average wedge crack growth of 0.04 and 0.01 inch respectively. A crack growth less than 0.05 inch is considered to be negligible. The degree of improvement for the weldbond/BR-127 system is tremendous when compared to the 2.0-inch crack growth for the unprimed weldbond system and the 1.60-inch crack growth of the FPL bonding system for the same 5 month exposure time.

## Weldbond Properties With and Without BR-127 Primer

For the third phase, lap-shear, T-peel and high-load transfer fatigue tests were conducted on panels which had been surface treated with and without the addition of the BR-127 primer, to determine if the primer would degrade the weldbond properties.

Lap-Shear Strength. Lap-shear specimens were weldbonded using 0.063-inch thick sheets of 7075-T6 bare. The lap-shear specimens were 1-inch wide with a 1-inch overlap. Tests were conducted at room temperature and -65F. The results are presented in Table 11. The lap-shear strength was almost equivalent for primed

## TABLE 10. TEST MATRIX FOR WELDBOND/BR-127 EVALUATION

| | | NUMBER OF SPECIMENS | |
|---|---|---|---|
| | | WITH BR-127 | WITHOUT BR-127 |
| **DURABILITY WEDGE TESTS** 2024-T3 ALCLAD TO 7075-T6 | 95F SALT FOG | 5 | 6* |
| | SEA COAST | 10 | 12* |
| **WELDBOND PROPERTY TESTS** 7075-T6 TO 7075-T6 | | | |
| LAP-SHEAR | ROOM TEMPERATURE | 5 | 5 |
| | -65F | 5 | 5 |
| T-PEEL | ASTM D1876 | 6 | 6 |
| FATIGUE | HIGH-LOAD TRANSFER | 8 | 5* |

*Data obtained from AFML-TR-79-4006 (Reference 4)

## TABLE 11. LAP-SHEAR STRENGTH FOR PRIMED AND UNPRIMED WELDBONDED 7075-T6

| TEST TEMPERATURE | LAP SHEAR STRENGTH (PSI) | |
|---|---|---|
| | WITH BR-127 | WITHOUT BR-127 |
| ROOM TEMPERATURE | 4920<br>4640<br>4540<br>4690<br>4690 | 4740<br>4990<br>4700<br>4800<br>4740 |
| AVERAGE | 4700 | 4790 |
| -65F | 3480<br>3670<br>4160<br>4060<br>2680 | 3640<br>4000<br>4330<br>3990<br>3310 |
| AVERAGE | 3610 | 3850 |

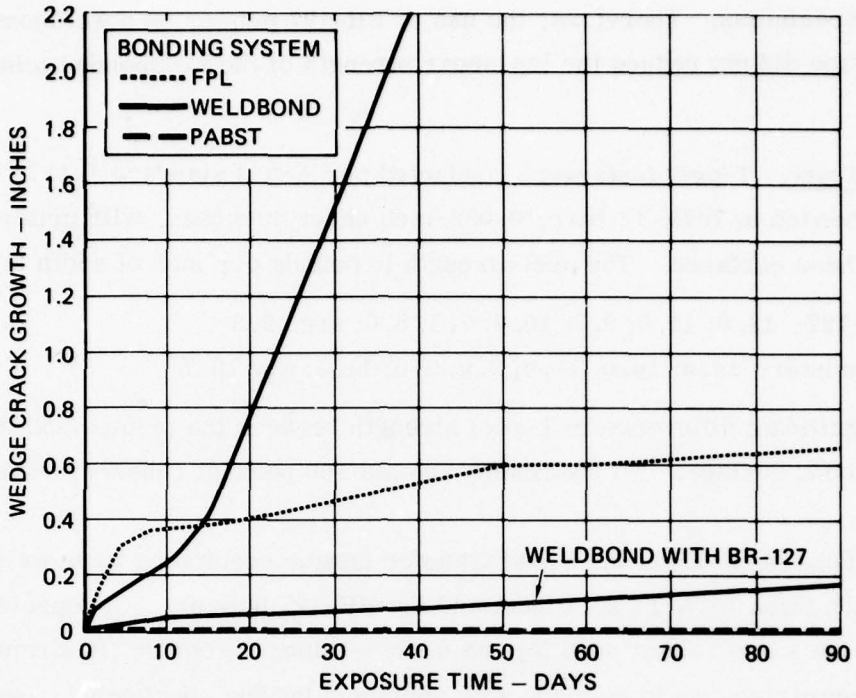



**FIGURE 18. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 ALCLAD/7075-T6 BARE INCLUDING WELDBOND/BR-127 — SALT FOG EXPOSURE**

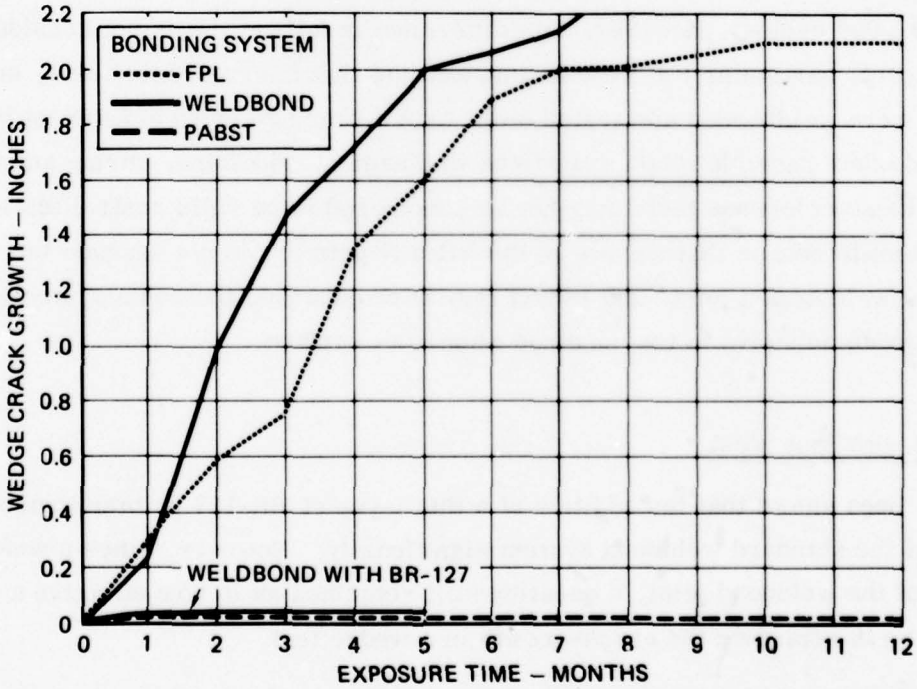



**FIGURE 19. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 ALCLAD/7075-T6 BARE INCLUDING WELDBOND/BR-127 — SEA COAST EXPOSURE**

and unprimed specimens. Therefore, the use of BR-127 primer on a weldbond prepared aluminum surface did not reduce the lap-shear strength of the weldbonded joint.

T-Peel Tests. T-peel tests were conducted per ASTM standard D 1876 using 7075-T6 bare bonded to 7075-T6 bare, 0.032-inch sheet thickness, with primed and unprimed weldbond surfaces. The peel strength in pounds per inch of width is as follows:

with BR-127: 13.0; 11.0; 9.5; 10.0; 7.5; 8.0; avg. 9.8
without primer: 14.0; 10.0; 11.0; 9.0; 9.0; 11.5; avg 10.7

There is no significant difference in T-peel strength between the primed and the unprimed weldbond surface. All specimens showed 100 percent cohesive failure.

Fatigue Behavior. Eight high-load transfer fatigue specimens were weldbonded using 0.063-inch thick 7075-T6 aluminum and the BR-127 primer. The specimen configuration was the same as that used for the basic weldbond program (Reference 4) so that a direct comparison could be made with unprimed fatigue specimens. Lap joint dimensions were 1.25 inches wide x 1.25 inches overlap and a single spot weld was used. The fatigue results are shown in Table 12. The average fatigue life for the primed specimens was higher than that of the unprimed specimens, i.e., 328,000 cycles vs 197,000 cycles. However, this difference in fatigue life is not considered to be significant, particularly if we take into account that the reference tests, unprimed specimens, were weldbonded and tested more than a year ago using a different batch of adhesive and other possible slight variations in cleaning, anodizing, curing and testing. Therefore, these reference tests may not be considered to be valid control tests. The important point to note is that the use of the BR-127 primer did not degrade the fatigue behavior of a weldbonded joint, and in fact may have enhanced the bonding strength of the A1444B paste adhesive to the anodized aluminum surface.

## Wedge Test with Spot Weld

It has been shown that the addition of a thin layer of BR-127 primer improved the durability of the standard weldbond system significantly. However, since a weld nugget is part of the weldbond joint, a question still remained as to how effective a spot weld would be in retarding the crack-growth in a wedge test.

Five wedge specimens were fabricated using the standard weldbond surface preparation and paste adhesive A1444B with 2024-T3 alclad and 7075-T6 bare. Spot

## TABLE 12. HIGH-LOAD TRANSFER FATIGUE BEHAVIOR FOR PRIMED AND UNPRIMED WELDBONDED 7075-T6

R: 0.1
FREQUENCY: 10 HZ
MAXIMUM LOAD: 2,250 LBS.

| PRIMED SPECIMENS | FATIGUE LIFE (CYCLES) | NUGGET DIAMETER MAX/MIN (INCH) |
|---|---|---|
| 1 | 350,510 | 0.25/0.25 |
| 2 | 398,240 | 0.31/0.29 |
| 3 | 446,530 | 0.35/0.32 |
| 4 | 332,950 | 0.32/0.32 |
| 5 | 394,810 | 0.34/0.30 |
| 6 | 256,320 | 0.32/0.30 |
| 7 | 186,200 | 0.37/0.31 |
| 8 | 256,090 | 0.31/0.27 |
| AVERAGE | 327,706 | |
| **UNPRIMED SPECIMENS (1)** | **FATIGUE LIFE (CYCLES)** | **NUGGET DIAMETER (INCH)** |
| 1 | 130,970 | 0.28 |
| 2 | 133,670 | 0.34 |
| 3 | 187,780 | 0.31 |
| 4 | 235,230 | 0.32 |
| 5 | 296,120 | 0.30 |
| AVERAGE | 196,754 | |

(1) Data obtained from AFML-TR-79-4006 (Reference 4)

welds were centered 3 inches from the end of the 6-inch specimen as shown in Figure 20. The average initial crack length was 2.25 inches, therefore, the edge of the spot weld nugget was approximately 0.5 inch from the initial crack tip created by the wedge. These specimens were exposed to the 5 percent salt fog environment.

The results of these wedge tests are shown in Figure 20 along with the wedge test results for the standard weldbond system, the weldbond system with BR-127, and the PABST system for comparison purposes. After 13 days the crack had progressed up to the edge of the weld nugget, i.e., 0.52 inch. After 183 days (6 months) the crack progressed only a small additional amount to 0.60 inch. The spot weld restrained the wedge crack-growth for at least six months of exposure to the salt fog after the crack tip reached the nugget. Therefore, the weldbond system, which utilizes spot welds is very effective in retarding crack-growth that might occur along the adhesive bonded joint with the standard weldbond surface preparation.

Conclusions for the Weldbond Durability Improvement Study

1. The environmental-stress durability of the weldbond system in both the 95F salt fog and the sea coast environment is significantly improved by the addition of a thin (0.00004-inch) layer of BR-127 primer to the anodized surface.
2. The addition of a thin layer of BR-127 primer to the standard weldbond surface preparation does not reduce lap-shear strength, T-peel strength, or high-load transfer fatigue life for weldbonded panels.
3. High quality welds can easily be made through a thin (0.00004-inch) layer of air dried BR-127 primer added to the standard weldbond surface treatment.
4. Spot welds in weldbond wedge specimens are effective in retarding crack growth in a stress-corrosion environment.

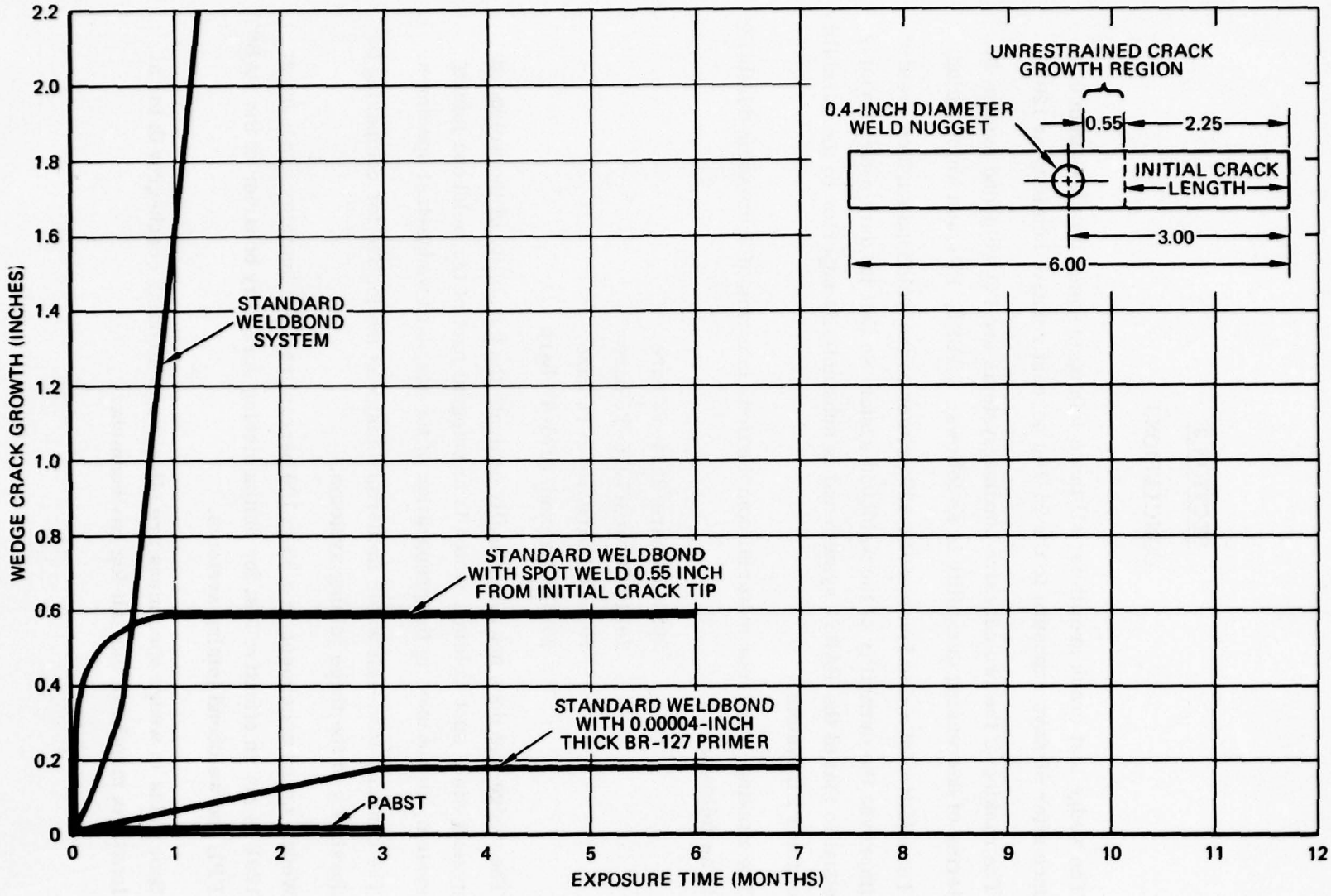



**FIGURE 20. AVERAGE WEDGE CRACK GROWTH OF 2024-T3 ALCLAD/7075-T6 BARE WELDBOND WITH SPOT WELD - SALT FOG EXPOSURE**

## SECTION 3

## CONCLUSIONS

1. The wedge test crack growth for all three joining systems was less than 0.5 inch after 90 days exposure to the 95-100 percent relative humidity at 120F.

2. The ranking of the two adhesive bonding systems and the weldbond system in terms of decreasing durability is as follows: PABST, FPL and weldbonding.

3. The addition of a thin layer of BR-127 primer to the weldbond surface greatly improves the durability of the weldbond system so that its durability is nearly equal to that of the PABST system and is substantially superior to the durability of the FPL system.

4. The ranking of the four material combinations in terms of decreasing durability is as follows:

   2024-T3 bare/2024-T3 bare
   2024-T3 bare/7075-T6 bare
   7075-T6 bare/7075-T6 bare
   2024-T3 alclad/7075-T6 bare

5. The wedge test does not realistically evaluate the durability of the weldbond system since spot welding, which is an integral part of the weldbond joining system, is not used in the preparation of the standard wedge-test specimen.

6. The constant load-salt water immersion test was ineffective for comparing the durability of the three joining systems.

7. Wedge-crack specimens in a 95 to 100 percent relative humidity exposure at 120F is not an effective test for distinguishing durability behavior of the PABST, FPL and weldbond joining systems.

8. Spot welds in wedge specimens are effective in stopping crack-growth for at least six months in the salt fog environment.

## REFERENCES


(1) "Primary Adhesively Bonded Structure Technology," Contract No. F33615-75-C-3016, (June 1979).

(2) Bowen, B. B., Herfert, R. E., and Wu, K. C., "Development of Corrosion Resistant Surface Treatments for Aluminum Alloys for Spot-Weld Bonding," Report No. AFML-TR-75-69, (March 1975).

(3) Wu, K. C., "Advanced Aluminum Weldbond Manufacturing Methods," Report No. AFML-TR-76-131, (September 1976).

(4) Croucher, T. R., "Advanced Weldbonding Process Establishment for Aluminum," Report No. AFML-TR-79-4006, (April 1979).

# APPENDIX A

## WEDGE TEST DATA

TABLE A1 WEDGE TEST DATA - SEA COAST EXPOSURE - 2024-T3 ALCLAD/7075-T6 BARE

FPL BONDING SYSTEM

ADHESIVE SYSTEM: FPL Etch - BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 29 March, 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| A1 | 0.006 | 1.90 | 0.20 | 1.15 | 1.25 | 1.25 | 1.45 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | (1) |
| A2 | 0.009 | 1.92 | 0.25 | 0.25 | 0.30 | 1.05 | 1.30 | 1.40 | 1.40 | 1.40 | 1.40 | 1.70 | 1.70 | 1.70 | (2) |
| A3 | 0.009 | 1.95 | 0.55 | 1.20 | 1.35 | 1.40 | 1.50 | 1.60 | 1.60 | 1.60 | 1.60 | 1.70 | 1.70 | 1.70 | (1) |
| A4 | 0.008 | 1.95 | 0.22 | 0.55 | 0.98 | 1.10 | 1.20 | 1.20 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | (1) |
| A5 | 0.007 | 2.02 | 0.19 | 0.23 | 0.23 | 1.15 | 1.35 | 1.50 | 1.80 | 1.80 | 2.20 | 2.30 | 2.30 | 2.30 | (2) |
| A6 | 0.007 | 1.90 | 0.20 | 0.31 | 0.31 | 0.60 | 0.85 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | (1) |
| A7 | 0.010 | 1.91 | 0.18 | 0.21 | 0.25 | 1.95 | 2.50 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | (2) |
| A8 | 0.010 | 1.92 | 0.22 | 0.23 | 1.20 | 1.80 | 2.30 | 2.50 | 2.50 | 2.60 | 2.60 | 2.70 | 2.70 | 2.70 | (2) |
| A9 | 0.008 | 1.99 | 0.72 | 1.15 | Discontinued(1) | | | | | | | | | | |
| A10 | 0.008 | 1.96 | 0.15 | 0.90 | 1.48 | 2.15 | 2.20 | 2.80 | 3.40 | 3.40 | 3.40 | 3.40 | 3.40 | 3.40 | (2) |
| A11 | 0.006 | 1.94 | 0.13 | 0.20 | 0.25 | 1.05 | 1.30 | 2.10 | 2.10 | 2.10 | 2.20 | 2.20 | 2.20 | 2.20 | (2) |
| A12 | 0.008 | 1.92 | 0.52 | Discontinued (1) | | | | | | | | | | | |
| Average | | | 0.29 | 0.58 | 0.76 | 1.35 | 1.60 | 1.89 | 2.00 | 2.01 | 2.05 | 2.11 | 2.11 | 2.11 | |
| Range | | | 0.13 | 0.21 | 0.23 | 0.60 | 0.85 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | |
| | | | 0.72 | 1.20 | 1.48 | 2.15 | 2.50 | 3.20 | 3.40 | 3.40 | 3.40 | 3.40 | 3.40 | 3.40 | |

(1) Failure mode was 80 to 100 percent adhesive failure along the 2024-T3 alclad surface.

(2) Failure mode was 80 to 100 percent adhesive failure along the 7075-T6 surface.

TABLE A2 WEDGE TEST DATA - SEA COAST EXPOSURE - 2024-T3 ALCLAD/7075-T6 BARE

WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0 - 1.5 Volt Phosphoric Acid Anodize/A1444B Paste Adhesive

EXPOSURE STARTED: 1 June, 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M1 | 0.006 | 2.13 | 0.30 | .95 | 1.50 | 1.50 | 1.90 | 2.00 | 2.20 | 2.20 | 2.40 | 2.50 | 2.50 | 2.50 | (2) |
| M2 | 0.006 | 2.07 | 0.48 | 1.15 | 1.45 | 1.80 | 2.20 | 2.40 | 2.60 | 3.10 | 3.90 | Discontinued | | | (2) |
| M3 | 0.006 | 2.12 | 0.08 | 1.10 | 1.65 | 2.20 | 2.20 | 2.20 | 2.30 | 2.30 | 2.40 | 2.50 | 2.50 | 2.50 | (2) |
| M4 | 0.008 | 2.14 | 0.13 | 1.10 | 1.70 | 2.00 | 2.60 | 2.60 | 2.70 | 2.70 | 2.75 | 2.75 | 2.75 | 2.75 | (2) |
| M5 | 0.008 | 2.09 | 0.16 | 1.50 | 2.20 | 2.40 | 2.60 | 2.60 | 2.60 | 2.60 | 2.60 | 2.60 | 2.60 | 2.60 | (3) |
| M6 | 0.006 | 2.09 | 0.18 | 0.65 | 1.00 | 1.40 | 1.60 | 1.60 | 1.60 | 1.60 | 1.70 | 1.80 | 1.80 | 2.00 | (4) |
| M7 | 0.007 | 2.04 | 0.55 | 1.35 | 1.90 | 2.00 | 2.10 | 2.10 | 2.10 | 2.90 | 3.97 | Discontinued | | | (2) |
| M8 | 0.008 | 2.13 | 0.13 | 0.70 | 1.50 | 1.70 | 2.00 | 2.00 | 2.00 | 2.00 | 2.30 | 2.45 | 2.45 | 2.45 | (3) |
| M9 | 0.010 | 1.97 | 0.37 | 1.05 | 1.20 | 1.45 | 1.90 | 2.20 | 2.40 | 4.00 | Discontinued | | | | (2) |
| M10 | 0.010 | 2.00 | 0.14 | 0.85 | 1.30 | 1.45 | 1.70 | 1.70 | 1.80 | 1.90 | 2.00 | 2.00 | 2.00 | 2.00 | (3) |
| M11 | 0.005 | 2.19 | 0.20 | 0.65 | 0.85 | 0.90 | 0.90 | 1.00 | 1.00 | 1.20 | 1.20 | 1.40 | 1.60 | 1.90 | (4) |
| M12 | 0.005 | 2.08 | 0.16 | 1.05 | 1.60 | 1.80 | 2.30 | 2.50 | 2.60 | 2.80 | 2.80 | 3.30 | 3.90 | | (4) |
| Average (1) | | | .24 | 1.01 | 1.49 | 1.72 | 2.00 | 2.08 | 2.16 | 2.44 | 2.67 | 2.76 | 2.83 | 2.87 | |
| Range | | | .08 | .65 | .85 | .90 | .90 | 1.00 | 1.00 | 1.20 | 1.20 | 1.40 | 1.60 | 1.90 | |
| | | | .55 | 1.50 | 2.20 | 2.40 | 2.60 | 2.60 | 2.70 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | |

(1) Average values include values for specimens which were discontinued.

(2) Failure mode was 100 percent adhesive failure along the 2024-T3 alclad surface.

(3) Failure mode was 100 percent adhesive failure, 20 to 50 percent of which occurred along the 2024-T3 alclad surface.

(4) Failure mode was 100 percent adhesive failure, 80 percent of which occurred along the 2024-T3 alclad surface.

TABLE A3 WEDGE TEST DATA - SEA COAST EXPOSURE - 2024-T3 ALCLAD/7075-T6 BARE

PABST SYSTEM

ADHESIVE SYSTEM: 10 - 15 Volt Phosphoric Acid Anodize/BR-127 Primer/FM 73 Mat Adhesive

EXPOSURE STARTED: 29 March 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| I 1 | 0.007 | 2.07 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 2 | 0.007 | 2.03 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 3 | 0.009 | 2.08 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 4 | 0.008 | 2.02 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 5 | 0.007 | 2.08 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 6 | 0.007 | 2.05 | 0.03 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 7 | 0.008 | 2.03 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 8 | 0.009 | 2.06 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| I 9 | 0.007 | 2.08 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| I 10 | 0.008 | 2.05 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 11 | 0.008 | 2.07 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| I 12 | 0.008 | 2.04 | 0.0 | Discontinued | | | | | | | | | | |
| Average | | | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Range | | | 0.0<br>0.04 | 0.0<br>0.04 | 0.0<br>0.04 | 0.0<br>0.04 | 0.0<br>0.04 | 0.0<br>0.04 | 0.0<br>0.04 | 0.0<br>0.04 | 0.0<br>0.04 | 0.0<br>0.04 | 0.0<br>0.04 | 0.0<br>0.04 |

TABLE A4 WEDGE TEST DATA - SEA COAST EXPOSURE - 2024 - T3 BARE/7075 - T6 BARE

FPL BONDING SYSTEM

ADHESIVE SYSTEM: FPL Etch - BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 29 March, 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| B1 | 0.006 | 1.93 | 0.10 | 0.86 | 2.30 | 3.85 | Discontinued (2) | | | | | | | | |
| B2 | 0.010 | 1.88 | 0.18 | 0.18 | 0.75 | 1.75 | 2.00 | 2.20 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | (2) |
| B3 | 0.008 | 1.87 | 0.13 | 0.16 | 0.16 | 0.25 | 0.40 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | (2) |
| B4 | 0.008 | 1.93 | 0.10 | 0.11 | 1.10 | 1.85 | 2.60 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | 3.20 | (2) |
| B5 | 0.007 | 1.95 | 0.16 | 0.16 | 1.35 | 2.50 | 4.05 | Discontinued (2) | | | | | | | |
| B6 | 0.005 | 1.92 | 0.13 | 0.14 | 1.25 | 1.80 | 2.20 | 2.50 | 2.70 | 2.70 | 2.70 | 2.70 | 2.70 | 2.70 | (2) |
| B7 | 0.010 | 1.95 | 0.10 | 0.08 | 0.12 | 0.90 | 1.00 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | (2) |
| B8 | 0.010 | 1.94 | 0.10 | 0.10 | 0.25 | 0.30 | 0.70 | 1.10 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | (2) |
| B9 | 0.009 | 1.93 | 0.10 | 0.10 | 0.12 | 0.20 | 0.70 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | (2) |
| B10 | 0.007 | 1.99 | 0.15 | 0.15 | 1.30 | 2.80 | 4.0 | Discontinued (2) | | | | | | | |
| B11 | 0.006 | 1.99 | 0.12 | 0.85 | Discontinued (2) | | | | | | | | | | |
| B12 | 0.010 | 1.95 | 0.13 | Discontinued | | | | | | | | | | | |
| Average (1) | | | 0.13 | 0.26 | 0.87 | 1.62 | 1.96 | 2.17 | 2.24 | 2.24 | 2.24 | 2.24 | 2.24 | 2.24 | |
| Range | | | 0.10<br>0.18 | 0.10<br>0.86 | 0.12<br>2.30 | 0.20<br>3.85 | 0.40<br>4.05 | 0.60<br>4.05 | 0.60<br>4.05 | 0.60<br>4.05 | 0.60<br>4.05 | 0.60<br>4.05 | 0.60<br>4.05 | 0.60<br>4.05 | |

(1) Average values include values for specimens B5 and B10.

(2) Failure mode was 80 to 100 percent adhesive failure along the 7075-T6 surface.

TABLE A5 WEDGE TEST DATA - SEA COAST EXPOSURE - 2024 - T3 BARE/7075-T6 BARE

WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0 - 1.5 Volt Phosphoric Acid Anodize/A1444B Paste Adhesive

EXPOSURE STARTED: 1 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| N1 | 0.009 | 2.19 | 0.05 | 1.20 | 1.70 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 (1) |
| N2 | 0.012 | 2.23 | 0.0 | 1.35 | 2.10 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 (1) |
| N3 | 0.015 | 2.16 | 0.0 | 1.20 | 1.50 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 (2) |
| N4 | 0.015 | 2.49 | 0.0 | 1.05 | 1.50 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 (1) |
| N5 | 0.013 | 2.75 | 0.0 | 0.75 | 1.30 | 1.50 | 1.50 | 1.70 | 1.70 | 1.90 | 2.00 | 2.00 | 2.00 | 2.00 (1) |
| N6 | 0.008 | 2.18 | 0.04 | 0.06 | 0.10 | 0.15 | 0.15 | 0.15 | 0.35 | 0.50 | 0.50 | 0.50 | 0.60 | 0.60 (2) |
| N7 | 0.011 | 2.38 | 0.0 | 0.0 | 0.0 | 0.0 | 0.70 | 0.70 | 0.70 | 0.70 | 0.70 | 0.80 | 0.80 | 0.90 (2) |
| N8 | 0.014 | 2.27 | 0.0 | 0.85 | 1.80 | 1.80 | 1.90 | 1.90 | 1.90 | 2.20 | 2.30 | 2.30 | 2.30 | 2.30 (1) |
| N9 | 0.012 | 2.17 | 0.0 | 0.0 | .10 | .40 | .80 | 1.00 | 1.00 | 1.10 | 1.30 | 1.30 | 1.30 | 1.60 (1) |
| N10 | 0.013 | 2.07 | 0.05 | 1.25 | 1.95 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 (1) |
| N11 | 0.015 | 2.18 | 0.10 | 0.90 | 1.65 | 1.80 | 1.90 | 2.30 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 (1) |
| N12 | 0.013 | 2.31 | 0.05 | 0.10 | 0.60 | 0.75 | 1.20 | 1.35 | 1.35 | 1.40 | 1.40 | 1.50 | 1.50 | 1.50 (1) |
| Average | | | 0.02 | 0.73 | 1.21 | 1.37 | 1.51 | 1.59 | 1.63 | 1.70 | 1.73 | 1.76 | 1.76 | 1.79 |
| Range | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.15 | 0.15 | 0.35 | 0.50 | 0.50 | 0.60 | 0.60 | 0.60 |
| | | | 0.10 | 1.35 | 2.10 | 2.30 | 2.30 | 2.30 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |

(1) Failure mode was 95 to 100 percent adhesive along the 7075-T6 surface.

(2) Failure mode was 100 percent adhesive failure.

TABLE A6 WEDGE TEST DATA - SEA COAST EXPOSURE - 2024 - T3 BARE/7075 - T6 BARE

PABST SYSTEM

ADHESIVE SYSTEM : 10 - 15 Volt Phosphoric Acid Anodize/ BR-127 Primer/ FM 73 Mat Adhesive

EXPOSURE STARTED: 29 March, 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| J1 | 0.006 | 2.17 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J2 | 0.008 | 2.08 | .02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| J3 | 0.008 | 2.11 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J4 | 0.007 | 2.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J5 | 0.006 | 2.14 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J6 | 0.003 | 2.19 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J7 | 0.006 | 2.02 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J8 | 0.007 | 2.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J9 | 0.007 | 2.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J10 | 0.007 | 2.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J11 | 0.006 | 2.12 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J12 | 0.007 | 2.15 | NC | Discontinued | | | | | | | | | | |
| Average | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Range | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | .02 | .02 | .02 | .02 | .02 | .02 | .02 | .02 | .02 | .02 | .02 | .02 |

TABLE A7 WEDGE TEST DATA - SEA COAST EXPOSURE - 2024 - T3 BARE/2024 - T3 BARE

FPL BONDING SYSTEM

ADHESIVE SYSTEM: FPL Etch - BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 29 March, 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| C1 | 0.008 | 1.89 | .15 | .15 | .15 | .15 | .15 | .20 | .30 | .30 | .40 | .50 | 0.50 | 0.50 (1) |
| C2 | 0.009 | 1.93 | .05 | .08 | .10 | .10 | .10 | .20 | .30 | .30 | .40 | .40 | 0.40 | 0.40 (1) |
| C3 | 0.010 | 1.88 | .05 | .10 | .13 | .90 | 1.10 | 1.40 | 1.40 | 1.40 | 1.50 | 1.50 | 1.50 | 1.50 (2) |
| C4 | 0.008 | 1.88 | .12 | .12 | .15 | .25 | .45 | .60 | .60 | .60 | .60 | .60 | 0.60 | 0.60 (1) |
| C5 | 0.007 | 1.91 | .11 | .11 | .15 | .90 | 1.10 | 1.30 | 1.30 | 1.40 | 1.50 | 1.50 | 1.50 | 1.50 (2) |
| C6 | 0.009 | 1.88 | .12 | .13 | .16 | .16 | .35 | .50 | .50 | .50 | .50 | .50 | 0.50 | 0.50 (3) |
| C7 | 0.009 | 1.90 | .15 | .15 | .15 | .25 | .35 | .35 | .35 | .35 | .35 | .50 | 0.50 | 0.50 (3) |
| C8 | 0.009 | 1.93 | .12 | .12 | .12 | .15 | .15 | .20 | .20 | .20 | .30 | .30 | 0.30 | 0.30 (1) |
| C9 | 0.008 | 1.93 | .08 | .12 | .15 | .20 | .75 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 (2) |
| C10 | 0.007 | 1.96 | .10 | .10 | .10 | .15 | .80 | .85 | .90 | .90 | .90 | .90 | 0.90 | 0.90 (2) |
| C11 | 0.009 | 1.93 | .12 | .12 | .20 | .30 | .35 | .60 | .60 | .60 | .60 | .60 | 0.60 | 0.60 (1) |
| C12 | 0.009 | 1.83 | .18 | Discontinued | | | | | | | | | | |
| Average | | | .11 | .12 | .14 | .32 | .51 | .65 | .68 | .69 | .73 | .75 | 0.75 | 0.77 |
| Range | | | .05 | .08 | .10 | .10 | .10 | .20 | .20 | .20 | .30 | .30 | 0.30 | 0.30 |
| | | | .18 | .15 | .20 | .90 | 1.10 | 1.40 | 1.40 | 1.40 | 1.50 | 1.50 | 1.50 | 1.60 |

(1) Failure mode was 40 to 60 percent adhesive failure.
(2) Failure mode was 80 to 100 percent adhesive failure.
(3) Failure mode was 20 to 40 percent adhesive failure.

TABLE A8 WEDGE TEST DATA - SEA COAST EXPOSURE - 2024 - T3 BARE/2024 - T3 BARE

WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0 - 1.5 Volt Phosphoric Acid Anodize/A1444B Paste Adhesive

EXPOSURE STARTED: 1 June, 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| 01 | 0.010 | 2.07 | 0.11 | 0.55 | 0.80 | 0.90 | 1.00 | 1.00 | 1.00 | 1.10 | 1.20 | 1.35 | 1.35 | 1.50 | (1) |
| 02 | 0.009 | 2.06 | 0.10 | 0.50 | 0.75 | 0.85 | 0.90 | 0.90 | 0.90 | 1.00 | 1.00 | 1.00 | 1.00 | 1.05 | (1) |
| 03 | 0.008 | 2.50 | 0.02 | 0.02 | 0.02 | 0.02 | 0.15 | 0.22 | 0.22 | 0.30 | 0.30 | 0.30 | 0.30 | 0.55 | (1) |
| 04 | 0.009 | 2.17 | 0.10 | 0.60 | 0.70 | 0.75 | 0.80 | 0.80 | 0.80 | 0.80 | 0.90 | 0.90 | 0.90 | 0.90 | (1) |
| 05 | 0.010 | 2.15 | 0.05 | 0.95 | 1.00 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 1.20 | 1.20 | 1.20 | 1.20 | (1) |
| 06 | 0.005 | 2.06 | 0.05 | 0.05 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.30 | 0.30 | 0.35 | 0.35 | 0.45 | (1) |
| 07 | 0.010 | 2.02 | 0.07 | 0.70 | 0.75 | 0.80 | 0.80 | 0.90 | 0.95 | 1.00 | 1.00 | 1.10 | 1.10 | 1.10 | (1) |
| 08 | 0.011 | 2.07 | 0.08 | 0.08 | 0.10 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.45 | 0.55 | 0.55 | 0.55 | (1) |
| 09 | 0.010 | 2.00 | 0.11 | 0.11 | 0.15 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.30 | 0.55 | 0.60 | 0.60 | (1) |
| 010 | 0.003 | 2.12 | 0.10 | 0.10 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | (2) |
| 011 | 0.009 | 2.11 | 0.08 | 0.55 | 0.95 | 1.05 | 1.45 | 1.60 | 1.60 | 1.80 | 1.80 | 1.90 | 1.90 | 2.20 | (1) |
| 012 | 0.009 | 2.12 | 0.15 | 0.15 | 0.50 | 0.60 | 0.65 | 0.80 | 0.90 | 1.10 | 1.20 | 1.50 | 1.65 | 2.20 | (1) |
| Average | | | 0.085 | 0.36 | 0.51 | 0.59 | 0.63 | 0.67 | 0.68 | 0.76 | 0.82 | 0.91 | 0.94 | 1.06 | |
| Range | | | 0.02 | .02 | 0.02 | 0.02 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | |
| | | | 0.15 | .95 | 1.00 | 1.10 | 1.45 | 1.60 | 1.60 | 1.80 | 1.80 | 1.90 | 1.90 | 2.20 | |

(1) Failure mode was 90 to 100 percent adhesive failure.

(2) Failure mode was 90 percent cohesive failure.

TABLE A9 WEDGE TEST DATA - SEA COAST EXPOSURE - 2024 - T3 BARE/2024 - T3 BARE

PABST SYSTEM

ADHESIVE SYSTEM: 10-15 Volt Phosphoric Acid Anodize/BR-127 Primer/FM73 Mat Adhesive

EXPOSURE STARTED: 29 March, 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| K1 | 0.008 | 2.13 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| K2 | 0.008 | 2.08 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| K3 | 0.008 | 2.05 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K4 | 0.008 | 2.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| K5 | 0.006 | 2.10 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| K6 | 0.004 | 2.08 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| K7 | 0.005 | 2.11 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| K8 | 0.005 | 2.16 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K9 | 0.006 | 2.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K10 | 0.007 | 2.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K11 | 0.005 | 2.12 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K12 | 0.007 | 2.08 | 0.0 | DISCONTINUED | | | | | | | | | | |
| Average | | | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Range | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |

TABLE A10 WEDGE TEST DATA - SEA COAST EXPOSURE - 7075 - T6 BARE/7075 - T6 BARE FPL BONDING SYSTEM

*ADHESIVE SYSTEM:* FPL Etch - BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 29 March, 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| D1 | 0.009 | 1.96 | 0.12 | 0.20 | 0.65 | 1.00 | 1.00 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | (2) |
| D2 | 0.010 | 1.98 | 0.14 | 0.65 | 1.40 | 2.35 | 2.75 | 3.50 | 3.50 | 3.60 | 3.60 | 3.60 | 3.60 | 3.70 | (2) |
| D3 | 0.010 | 1.97 | 0.10 | 0.78 | 1.80 | 3.10 | 4.0 DISCONTINUED | | | | | | | | (2) |
| D4 | 0.010 | 1.98 | 0.09 | 0.82 | 1.35 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | (2) |
| D5 | 0.010 | 1.98 | 0.08 | 0.08 | 0.75 | 1.45 | 1.80 | 2.10 | 2.10 | 2.10 | 2.10 | 2.10 | 2.10 | 2.10 | (2) |
| D6 | 0.008 | 1.93 | 0.13 | 0.65 | 1.20 | 1.50 | 1.65 | 1.70 | 1.70 | 1.75 | 1.75 | 1.75 | 1.75 | 1.75 | (2) |
| D7 | 0.010 | 1.92 | 0.14 | 0.14 | 1.45 | DISCONTINUED | | | | | | | | | (2) |
| D8 | 0.010 | 1.96 | 0.15 | 0.15 | 1.55 | 1.55 | 2.10 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | 2.30 | (2) |
| D9 | 0.010 | 1.91 | 0.13 | 0.83 | 1.35 | 1.65 | 1.75 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | (2) |
| D10 | 0.010 | 1.98 | 0.08 | 0.68 | 1.70 | 2.20 | 2.40 | 2.40 | 2.40 | 2.40 | 2.40 | 2.50 | 2.50 | 2.50 | (2) |
| D11 | 0.009 | 1.96 | 0.11 | 1.08 | DISCONTINUED | | | | | | | | | | (2) |
| D12 | 0.008 | 2.00 | 0.05 | DISCONTINUED | | | | | | | | | | | |
| Average(1) | | | 0.11 | 0.55 | 1.20 | 1.84 | 2.13 | 2.35 | 2.35 | 2.36 | 2.36 | 2.37 | 2.37 | 2.38 | |
| Range | | | 0.05 | 0.08 | 0.65 | 1.00 | 1.00 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | |
| | | | 0.15 | 1.08 | 1.80 | 3.10 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | |

(1) Average Values Include Values For Specimen D3.

(2) Failure mode was 100 percent adhesive failure.

TABLE A11 WEDGE TEST DATA - SEA COAST EXPOSURE - 7075-T6 BARE/7075-T6 BARE

WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0 - 1.5 Volt Phosphoric Acid Anodize/A1444B Paste Adhesive

EXPOSURE STARTED: 1 June, 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| P1 | 0.009 | 2.51 | 0.0 | 0.55 | 1.10 | 1.20 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | (1) |
| P2 | 0.011 | 2.15 | 0.02 | 1.15 | 1.80 | 2.00 | 2.00 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | (1) |
| P3 | 0.011 | 2.19 | 0.0 | 1.10 | 1.45 | 1.60 | 1.65 | 1.65 | 1.65 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 | (1) |
| P4 | 0.010 | 2.17 | 0.07 | 1.00 | 1.65 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | (1) |
| P5 | 0.010 | 2.43 | 0.0 | 0.95 | 1.30 | 1.55 | 1.55 | 1.55 | 1.55 | 1.60 | 1.60 | 1.60 | 1.60 | 1.60 | (1) |
| P6 | 0.009 | 2.25 | 0.0 | 1.20 | 1.75 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | (1) |
| P7 | 0.010 | 2.25 | 0.0 | 0.50 | 1.30 | 1.60 | 1.90 | 1.90 | 1.90 | 1.90 | 2.00 | 2.00 | 2.00 | 2.00 | (1) |
| P8 | 0.010 | 2.21 | 0.10 | 1.25 | 1.85 | 2.15 | 2.15 | 2.15 | 2.15 | 2.15 | 2.15 | 2.15 | 2.15 | 2.15 | (1) |
| P9 | 0.010 | 2.11 | 0.08 | 0.90 | 1.40 | 1.40 | 1.80 | 1.80 | 1.80 | 1.90 | 1.90 | 2.00 | 2.00 | 2.00 | (1) |
| P10 | 0.011 | 2.38 | 0.0 | 0.95 | 1.20 | 1.50 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 | 1.70 | (1) |
| P11 | 0.011 | 2.66 | 0.0 | 0.85 | 1.50 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | (1) |
| P12 | 0.012 | 2.38 | 0.0 | 1.15 | 1.50 | 1.90 | 1.90 | 1.90 | 1.90 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | (1) |
| Average | | | 0.024 | 0.96 | 1.48 | 1.74 | 1.85 | 1.85 | 1.85 | 1.88 | 1.89 | 1.90 | 1.90 | 1.90 | (1) |
| Range | | | 0.0 | 0.50 | 1.10 | 1.20 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | 1.40 | |
| | | | 0.10 | 1.25 | 1.85 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | 2.20 | |

(1) Failure mode was 100 percent adhesive failure.

TABLE A12 WEDGE TEST DATA - SEA COAST EXPOSURE - 7075-T6 BARE/7075-T6 BARE

PABST SYSTEM

ADHESIVE SYSTEM: 10-15 Volt Phosphoric Acid Anodize/BR-127 Primer/FM 73 Mat Adhesive

EXPOSURE STARTED: 29 March, 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| L1 | 0.005 | 2.16 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L2 | 0.007 | 2.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L3 | 0.008 | 2.08 | 0.0 | 0.0 | .05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| L4 | 0.007 | 2.07 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L5 | 0.003 | 2.14 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L6 | 0.005 | 2.16 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L7 | 0.008 | 2.15 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L8 | 0.008 | 2.13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L9 | 0.006 | 2.13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L10 | 0.002 | 2.14 | .04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| L11 | 0.006 | 2.13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L12 | 0.006 | 2.11 | 0.0 | DISCONTINUED | | | | | | | | | | |
| Average | | | 0.0 | 0.0 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Range | | | 0.0<br>0.04 | 0.0<br>0.04 | 0.0<br>0.05 | 0.0<br>0.05 | 0.0<br>0.05 | 0.0<br>0.05 | 0.0<br>0.05 | 0.0<br>0.05 | 0.0<br>0.05 | 0.0<br>0.05 | 0.0<br>0.05 | 0.0<br>0.05 |

TABLE A13 WEDGE TEST DATA - SALT FOG EXPOSURE -2024-T3 ALCLAD/7075-T6 BARE FPL BONDING SYSTEM

ADHESIVE SYSTEM: FPL Etch/BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 4 May 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) 1 | 4 | 8 | 15 | 30 | 50 | 60 | 90 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A 13 | (1) | 2.01 | 0.05 | 0.72 | 0.82 | 0.82 | 0.85 | 0.92 | 0.92 | 0.92 | (2) |
| A 14 | (1) | 1.96 | 0.08 | 0.18 | 0.21 | 0.38 | 0.55 | 0.70 | 0.70 | 0.70 | (2) |
| A 15 | (1) | 2.01 | 0.10 | 0.21 | 0.23 | 0.25 | 0.35 | 0.45 | 0.45 | 0.55 | (2) |
| A 16 | (1) | 1.96 | 0.11 | 0.18 | 0.25 | 0.05 | 0.25 | 0.40 | 0.40 | 0.45 | (2) |
| A 17 | (1) | 1.89 | 0.17 | 0.25 | 0.25 | 0.25 | 0.32 | 0.52 | 0.55 | 0.60 | (2) |
| A 18 | (1) | 1.85 | 0.21 | 0.24 | 0.31 | 0.32 | 0.40 | 0.60 | 0.60 | 0.65 | (2) |
| Average | | | 0.12 | 0.30 | 0.35 | 0.38 | 0.45 | 0.60 | 0.60 | 0.65 | |
| Range | | | 0.05 | 0.18 | 0.21 | 0.25 | 0.25 | 0.40 | 0.40 | 0.45 | |
| | | | 0.21 | 0.72 | 0.82 | 0.82 | 0.85 | 0.92 | 0.92 | 0.92 | |

(1) Bondline thickness ranged from 0.006-inch to 0.010-inch.

(2) 100 percent adhesive failure along the 2024-T3 alclad surface.

TABLE A14 WEDGE TEST DATA - SALT FOG EXPOSURE - 2024-T3 ALCLAD/7075-T6 BARE WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0-1.5 Volt Phosphoric Acid Anodize/A1444B Paste Adhesive Cured at 250-260 F for 2 1/2 Hours

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| M 13 | 0.008 | 2.10 | 0.06 | 0.15 | 0.15 | 0.75 | 2.20 | 3.10 | 3.90 | (1) | |
| M 14 | 0.007 | 2.08 | 0.15 | 0.20 | 0.27 | 0.35 | 0.45 | 2.70 | 2.70 | (1) | |
| M 15 | 0.007 | 2.11 | 0.10 | 0.15 | 0.37 | 0.45 | 2.20 | 2.50 | 2.70 | (1) | |
| M 16 | 0.008 | 2.00 | 0.0 | 0.05 | 0.20 | 0.20 | 2.10 | 2.70 | 2.80 | (1) | |
| M 17 | 0.009 | 2.12 | 0.13 | 0.13 | 0.25 | 0.25 | 0.35 | 2.80 | 2.80 | (1) | |
| M 18 | 0.009 | 2.06 | 0.11 | 0.15 | 0.25 | 0.50 | 2.10 | 2.90 | 4.00 | (1) | |
| Average | | | 0.09 | 0.14 | 0.25 | 0.42 | 1.56 | 2.78 | 3.15 | | |
| Range | | | 0.0 | 0.05 | 0.20 | 0.20 | 0.35 | 2.50 | 2.70 | | |
| | | | 0.15 | 0.20 | 0.37 | 0.75 | 2.20 | 3.10 | 4.00 | | |

(1 ) 100 percent adhesive failure along the 2024-T3 alclad surface.

TABLE A15 WEDGE TEST DATA - SALT FOG EXPOSURE - 2024-T3 ALCLAD/7075-T6 BARE PABST SYSTEM

ADHESIVE SYSTEM: 10-15 Volt Phosphoric Acid Anodize/BR-127 Primer/FM 73 Mat Adhesive

EXPOSURE STARTED: 4 May 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 8 | 15 | 30 | 50 | 60 | 90 |
| I 13 | (1) | 2.04 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 14 | (1) | 2.09 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 15 | (1) | 2.14 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 16 | (1) | 2.08 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 17 | (1) | 2.08 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 18 | (1) | 2.12 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Average | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Range | | | | | | | | | |

(1) Bondline thickness ranged from 0.005 to 0.009 inch.

TABLE A16 WEDGE TEST DATA - SALT FOG EXPOSURE-2024-T3 BARE/7075-T6 BARE FPL BONDING SYSTEM

ADHESIVE SYSTEM: FPL Etch /BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 4 May 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 8 | 15 | 30 | 50 | 60 | 90 | |
| B 13 | (1) | 1.93 | 0.12 | 0.15 | 0.22 | 0.26 | 0.35 | 0.45 | 0.50 | 0.65 | (2) |
| B 14 | (1) | 2.02 | 0.05 | 0.13 | 0.16 | 0.17 | 0.25 | 0.30 | 0.30 | 0.30 | (2) |
| B 15 | (1) | 1.99 | 0.12 | 0.17 | 0.21 | 0.23 | 0.30 | 0.30 | 0.30 | 0.40 | (2) |
| B 16 | (1) | 2.00 | 0.09 | 0.18 | 0.25 | 0.26 | 0.38 | 0.55 | 0.60 | 0.60 | (2) |
| B 17 | (1) | 1.97 | 0.06 | 0.13 | 0.18 | 0.22 | 0.50 | 0.60 | 0.65 | 0.65 | (2) |
| B 18 | (1) | 1.95 | 0.09 | 0.17 | 0.18 | 0.23 | 0.30 | 0.55 | 0.65 | 0.65 | (2) |
| | Average | | 0.09 | 0.16 | 0.20 | 0.23 | 0.35 | 0.46 | 0.50 | 0.54 | |
| | Range | | 0.06 | 0.13 | 0.16 | 0.17 | 0.25 | 0.30 | 0.30 | 0.30 | |
| | | | 0.12 | 0.18 | 0.25 | 0.26 | 0.50 | 0.60 | 0.65 | 0.65 | |

(1) Bondline thickness ranged from 0.006 inch to 0.010 inch.
(2) 100 percent adhesive failure with more than 80 percent occurring along the 2024-T3 bare.

TABLE A17 WEDGE TEST DATA - SALT FOG EXPOSURE - 2024-T3 BARE/7075-T6 BARE

WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0-1.5 Volt Phosphoric Acid Anodize/A1444B Paste Adhesive Cured at 270-290 F for 1 Hour

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 | |
| N 13 | 0.013 | 2.56 | 0.0 | 0.0 | 0.0 | 1.15 | 1.30 | 1.30 | 1.40 | 1.40 | (1) |
| N 14 | 0.013 | 2.16 | 0.10 | 0.10 | 0.85 | 1.60 | 1.80 | 1.80 | 1.80 | 1.80 | (1) |
| N 15 | 0.013 | 2.71 | 0.0 | 0.0 | 0.0 | 0.02 | 0.05 | 0.10 | 1.50 | 1.50 | (1) |
| N 16 | 0.013 | 2.42 | 0.0 | 0.0 | 0.0 | 0.0 | 1.10 | 1.30 | 1.30 | 1.30 | (1) |
| N 17 | 0.013 | 2.26 | 0.0 | 0.0 | 0.80 | 0.80 | 0.95 | 1.10 | 1.30 | 1.30 | (1) |
| N 18 | 0.016 | 2.81 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| Average | | | 0.02 | 0.02 | 0.28 | 0.60 | 0.87 | 0.93 | 1.21 | 1.21 | |
| Range | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| | | | 0.10 | 0.10 | 0.85 | 1.60 | 1.80 | 1.80 | 1.80 | 1.80 | |

(1) 100 percent adhesive failure along the 2024-T3 bare surface.

TABLE A18 WEDGE TEST DATA - SALT FOG EXPOSURE - 2024-T3 BARE/7075-T6 BARE

PABST SYSTEM

ADHESIVE SYSTEM: 10-15 Volt Phosphoric Acid Anodize/BR-127 Primer/FM 73 Mat Adhesive

EXPOSURE STARTED: 4 May 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 8 | 15 | 30 | 50 | 60 | 90 |
| J 13 | (1) | 2.19 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J 14 | (1) | 2.26 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J 15 | (1) | 2.29 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J 16 | (1) | 2.14 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J 17 | (1) | 2.13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J 18 | (1) | 2.13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Range | | | | | | | | | | |

(1) Bondline thickness ranged from 0.005 to 0.009 inch.

TABLE A19 WEDGE TEST DATA - SALT FOG EXPOSURE - 2024-T3 BARE/2024-T3 BARE FPL BONDING SYSTEM

ADHESIVE SYSTEM: FPL Etch/BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 4 May 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) 1 | 4 | 8 | 15 | 30 | 50 | 60 | 90 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C 13 | (1) | 1.90 | 0.07 | 0.13 | 0.16 | 0.16 | 0.22 | 0.40 | 0.55 | 0.60 | (2) |
| C 14 | (1) | 1.91 | 0.08 | 0.13 | 0.17 | 0.19 | 0.20 | 0.35 | 0.43 | 0.50 | (2) |
| C 15 | (1) | 1.92 | 0.12 | 0.20 | 0.21 | 0.24 | 0.25 | 0.35 | 0.35 | 0.45 | (2) |
| C 16 | (1) | 1.92 | 0.09 | 0.13 | 0.17 | 0.19 | 0.20 | 0.30 | 0.35 | 0.50 | (2) |
| C 17 | (1) | 1.89 | 0.12 | 0.17 | 0.21 | 0.23 | 0.30 | 0.40 | 0.50 | 0.60 | (2) |
| C 18 | (1) | 1.87 | 0.12 | 0.16 | 0.22 | 0.25 | 0.40 | 0.55 | 0.55 | 0.65 | (2) |
| | Average | | 0.10 | 0.15 | 0.19 | 0.21 | 0.26 | 0.39 | 0.46 | 0.55 | |
| | Range | | 0.07 | 0.13 | 0.16 | 0.16 | 0.20 | 0.30 | 0.35 | 0.45 | |
| | | | 0.12 | 0.20 | 0.22 | 0.25 | 0.40 | 0.55 | 0.55 | 0.65 | |

(1) Bondline thickness ranged from 0.006 inch to 0.010 inch.
(2) 100 percent adhesive failure.

TABLE A20 WEDGE TEST DATA - SALT FOG EXPOSURE - 2024-T3 BARE/2024-T3 BARE WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0-1.5 Volt Phosphoric Acid Anodize/A1444B Paste Adhesive Cured at 250-260 F For 2-1/2 Hours

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| O 13 | 0.009 | 2.10 | 0.14 | 0.15 | 0.28 | 0.30 | 0.35 | 0.45 | 0.45 | 0.50 | (1) |
| O 14 | 0.008 | 2.08 | 0.08 | 0.15 | 0.27 | 0.30 | 0.30 | 0.55 | 0.55 | 0.60 | (1) |
| O 15 | 0.009 | 2.14 | 0.03 | 0.05 | 0.15 | 0.20 | 0.35 | 0.50 | 0.50 | 0.50 | (1) |
| O 16 | 0.008 | 2.08 | 0.15 | 0.15 | 0.20 | 0.20 | 0.30 | 0.45 | 0.45 | 0.50 | (1) |
| O 17 | 0.008 | 2.04 | 0.06 | 0.10 | 0.18 | 0.18 | 0.20 | 0.30 | 0.30 | 0.40 | (1) |
| O 18 | 0.008 | 2.05 | 0.08 | 0.15 | 0.18 | 0.18 | 0.20 | 0.50 | 0.50 | 0.50 | (1) |
| | Average | | 0.09 | 0.13 | 0.21 | 0.23 | 0.28 | 0.46 | 0.46 | 0.50 | |
| | Range | | 0.03 | 0.05 | 0.15 | 0.18 | 0.20 | 0.30 | 0.30 | 0.40 | |
| | | | 0.15 | 0.15 | 0.28 | 0.30 | 0.35 | 0.55 | 0.55 | 0.60 | |

(1) 90 to 95 percent cohesive failure.

TABLE A21 WEDGE TEST DATA - SALT FOG EXPOSURE - 2024-T3 BARE/2024-T3 BARE PABST SYSTEM

ADHESIVE SYSTEM: 10-15 Volt Phosphoric Acid Anodize/BR-127 Primer/FM 73 Mat Adhesive

EXPOSURE STARTED: 4 May 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 8 | 15 | 30 | 50 | 60 | 90 |
| K13 | (1) | 2.13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K14 | (1) | 2.14 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K15 | (1) | 2.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.05 | 0.05 | 0.05 | 0.05 |
| K16 | (1) | 2.12 | 0.0 | 0.0 | 0.0 | 0.0 | 0.06 | 0.06 | 0.06 | 0.06 |
| K17 | (1) | 2.11 | 0.0 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| K18 | (1) | 2.10 | 0.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| | Average | | 0.0 | 0.01 | 0.01 | 0.01 | 0.03 | 0.03 | 0.03 | 0.03 |
| | Range | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | | 0.03 | 0.03 | 0.03 | 0.06 | 0.06 | 0.06 | 0.06 |

(1) Bondline thickness ranged from 0.005 to 0.009 inch.

TABLE A22 WEDGE TEST DATA - SALT FOG EXPOSURE - 7075-T6 BARE/7075-T6 BARE FPL BONDING SYSTEM

ADHESIVE SYSTEM: FPL Etch/BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 4 May 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 8 | 15 | 30 | 50 | 60 | 90 | |
| D13 | (1) | 2.00 | 0.08 | 0.15 | 0.20 | 0.20 | 0.20 | 0.25 | 0.30 | 0.45 | (2) |
| D14 | (1) | 2.04 | 0.08 | 0.13 | 0.18 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | (2) |
| D15 | (1) | 2.04 | 0.07 | 0.08 | 0.17 | 0.18 | 0.20 | 0.30 | 0.30 | 0.35 | (2) |
| D16 | (1) | 2.03 | 0.10 | 0.20 | 0.21 | 0.23 | 0.23 | 0.25 | 0.25 | 0.30 | (2) |
| D17 | (1) | 1.98 | 0.13 | 0.15 | 0.15 | 0.23 | 0.25 | 0.35 | 0.35 | 0.45 | (2) |
| D18 | (1) | 2.08 | 0.06 | 0.10 | 0.21 | 0.21 | 0.21 | 0.25 | 0.25 | 0.25 | (2) |
| | Average | | 0.09 | 0.14 | 0.18 | 0.23 | 0.23 | 0.28 | 0.29 | 0.35 | |
| | Range | | 0.06 | 0.08 | 0.12 | 0.18 | 0.20 | 0.25 | 0.25 | 0.25 | |
| | | | 0.13 | 0.20 | 0.21 | 0.30 | 0.30 | 0.35 | 0.35 | 0.45 | |

(1) Bondline thickness ranged from 0.006-inch to 0.010-inch.

(2) 100 percent adhesive failure.

TABLE A23 WEDGE TEST DATA - SALT FOG EXPOSURE - 7075-T6 BARE/7075-T6 BARE WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0 - 1.5 Volt Phosphoric Acid Anodize/A1444B Paste Adhesive Cured at 270-290°F for 1 Hour

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| P13 | 0.013 | 2.52 | 0.0 | 0.05 | 0.05 | 0.45 | 1.40 | 1.40 | 1.40 | 1.40 | (1) |
| P14 | 0.011 | 2.15 | 0.12 | 0.15 | 0.35 | 0.65 | 1.50 | 1.70 | 1.70 | 1.70 | (1) |
| P15 | 0.009 | 2.15 | 0.08 | 0.12 | 0.15 | 0.15 | 0.90 | 1.55 | 1.55 | 1.60 | (1) |
| P16 | 0.010 | 2.14 | 0.08 | 0.10 | 0.35 | 0.80 | 0.90 | 0.90 | 0.90 | 0.90 | (1) |
| P17 | 0.013 | 2.81 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| P18 | 0.014 | 2.36 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.40 | 1.10 | 1.10 | (1) |
| Average | | | 0.05 | 0.06 | 0.15 | 0.34 | 0.78 | 0.99 | 1.10 | 1.11 | |
| Range | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | |
| | | | 0.12 | 0.15 | 0.35 | 0.80 | 1.50 | 1.70 | 1.70 | 1.70 | |

(1) 100 percent adhesive failure.

TABLE A24 WEDGE TEST DATA - SALT FOG EXPOSURE - 7075-T6 BARE/7075-T6 BARE PABST SYSTEM

ADHESIVE SYSTEM: 10-15 Volt Phosphoric Acid Anodize/BR-127 Primer/FM 73 Mat Adhesive

EXPOSURE STARTED: 4 May 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) 1 | 4 | 8 | 15 | 30 | 50 | 60 | 90 |
|---|---|---|---|---|---|---|---|---|---|---|
| L13 | (1) | 2.15 | 0.0 | 0.0 | 0.0 | 0.0 | 0.10 | 0.10 | 0.10 | 0.10 |
| L14 | (1) | 2.18 | 0.0 | 0.0 | 0.0 | 0.0 | 0.05 | 0.05 | 0.05 | 0.05 |
| L15 | (1) | 2.18 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L16 | (1) | 2.16 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L17 | (1) | 2.11 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L18 | (1) | 2.13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.03 | 0.03 | 0.03 | 0.03 |
| Range | | | — | — | — | — | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | | | | | 0.10 | 0.10 | 0.10 | 0.10 |

(1) Bondline thickness ranged from 0.005 to 0.009 inch

TABLE A25 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 2024-T3 ALCLAD/7075-T6 BARE-FPL BONDING SYSTEM

ADHESIVE SYSTEM: FPL Etch/BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| A25 | 0.008 | 2.02 | 0.10 | 0.12 | 0.17 | 0.15 | 0.15 | 0.15 | 0.15 | 0.30 |
| A26 | 0.007 | 2.03 | 0.12 | 0.17 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.25 |
| A27 | 0.009 | 1.98 | 0.13 | 0.18 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.29 |
| A28 | 0.009 | 1.95 | 0.14 | 0.17 | 0.20 | 0.21 | 0.21 | 0.21 | 0.21 | 0.28 |
| A29 | 0.008 | 1.98 | 0.09 | 0.10 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.21 |
| A30 | 0.008 | 1.98 | 0.13 | 0.16 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.25 |
| Average | | | 0.11 | 0.15 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.26 |
| Range | | | 0.09 | 0.10 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.21 |
| | | | 0.14 | 0.18 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.30 |

TABLE A26 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 2024-T3 ALCLAD/7075-T6 BARE-WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0-1.5 Volt Phosphoric Acid Anodize/A-1444B Paste Adhesive Cured at 250-260F for 2-1/2 Hours

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| M25 | 0.007 | 2.38 | 0.0 | 0.05 | 0.06 | 0.15 | 0.15 | 0.15 | 0.15 | 0.35 |
| M26 | 0.008 | 2.13 | 0.0 | 0.13 | 0.16 | 0.20 | 0.25 | 0.25 | 0.25 | 0.38 |
| M27 | 0.010 | 2.38 | 0.0 | 0.0 | 0.0 | 0.0 | 0.08 | 0.08 | 0.08 | 0.27 |
| M28 | 0.010 | 2.22 | 0.0 | 0.07 | 0.08 | 0.10 | 0.10 | 0.13 | 0.13 | 0.36 |
| M29 | 0.009 | 2.28 | 0.02 | 0.15 | 0.15 | 0.15 | 0.20 | 0.20 | 0.20 | 0.47 |
| M30 | 0.007 | 2.10 | 0.15 | 0.21 | 0.27 | 0.30 | 0.38 | 0.40 | 0.40 | 0.68 |
| Average | | | 0.03 | 0.10 | 0.12 | 0.15 | 0.19 | 0.20 | 0.20 | 0.42 |
| Range | | | 0.0 | 0.0 | 0.0 | 0.08 | 0.08 | 0.08 | 0.08 | 0.27 |
| | | | 0.15 | 0.21 | 0.27 | 0.30 | 0.38 | 0.40 | 0.40 | 0.68 |

TABLE A27 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 2024-T3 ALCLAD/7075-T6 BARE - PABST SYSTEM

ADHESIVE SYSTEM: 10-15 Volt Phosphoric Acid Anodize/BR-127 Primer/FM 73 Mat Adhesive

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| I 25 | 0.008 | 2.10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| I 26 | 0.009 | 2.15 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.06 |
| I 27 | 0.010 | 2.11 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.05 |
| I 28 | 0.010 | 2.08 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.05 |
| I 29 | 0.009 | 2.12 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.05 |
| I 30 | 0.007 | 2.11 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | Average | | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.04 |
| | Range | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.06 |

TABLE A28 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 2024-T3 BARE/7075-T6 BARE - FPL BONDING SYSTEM

ADHESIVE SYSTEM: FPL Etch/BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| B 25 | 0.009 | 2.00 | 0.12 | 0.12 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.21 |
| B 26 | 0.008 | 1.99 | 0.15 | 0.15 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.27 |
| B 27 | 0.010 | 1.99 | 0.12 | 0.14 | 0.16 | 0.17 | 0.17 | 0.17 | 0.17 | 0.28 |
| B 28 | 0.010 | 2.00 | 0.11 | 0.11 | 0.16 | 0.16 | 0.18 | 0.18 | 0.18 | 0.27 |
| B 29 | 0.010 | 1.98 | 0.11 | 0.12 | 0.16 | 0.16 | 0.17 | 0.17 | 0.17 | 0.24 |
| B 30 | 0.006 | 1.99 | 0.12 | 0.13 | 0.17 | 0.17 | 0.18 | 0.18 | 0.18 | 0.23 |
| | Average | | 0.12 | 0.13 | 0.17 | 0.17 | 0.18 | 0.18 | 0.18 | 0.25 |
| | Range | | 0.11 | 0.11 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | 0.21 |
| | | | 0.15 | 0.15 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.28 |

TABLE A29 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 2024-T3 BARE/7075-T6 BARE - WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0-1.5 Volt Phosphoric Acid Anodize/A1444B Paste Adhesive cured at 270-290 F for 1 Hour.

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| N 25 | 0.008 | 2.25 | 0.10 | 0.12 | 0.13 | 0.13 | 0.15 | 0.15 | 0.15 | 0.42 |
| N 26 | 0.015 | 2.58 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.08 |
| N 27 | 0.017 | 2.62 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.04 |
| N 28 | 0.018 | 2.48 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.10 |
| N29 | 0.019 | 2.16 | 0.0 | 0.08 | 0.08 | 0.08 | 0.09 | 0.09 | 0.09 | 0.22 |
| N 30 | 0.012 | 2.28 | 0.0 | 0.06 | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.18 |
| | | Average | 0.02 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.17 |
| | | Range | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.04 |
| | | | 0.10 | 0.12 | 0.13 | 0.13 | 0.15 | 0.15 | 0.15 | 0.42 |

TABLE A30 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 2024-T3 BARE/7075-T6 BARE - PABST SYSTEM

ADHESIVE SYSTEM: 10-15 Volt Phosphoric Acid Anodize/BR-127 Primer/FM 73 Mat Adhesive

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| J 25 | 0.004 | 2.12 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.03 |
| J 26 | 0.006 | 2.09 | 0.0 | 0.0 | 0.0 | 0.0 | 0.06 | 0.06 | 0.06 | 0.06 |
| J 27 | 0.007 | 2.12 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| J 28 | 0.007 | 2.14 | 0.0 | 0.0 | 0.0 | 0.0 | 0.05 | 0.05 | 0.05 | 0.08 |
| J 29 | 0.006 | 2.16 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.07 |
| J 30 | 0.006 | 2.11 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | Average | 0.0 | 0.0 | 0.0 | 0.0 | 0.02 | 0.02 | 0.02 | 0.04 |
| | | Range | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.06 | 0.06 | 0.06 | 0.08 |

TABLE A31 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 2024-T3 BARE/2024-T3 BARE - FPL BONDING SYSTEM

ADHESIVE SYSTEM: FPL Etch /BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| C 25 | 0.007 | 2.01 | 0.06 | 0.06 | 0.11 | 0.13 | 0.13 | 0.13 | 0.13 | 0.18 |
| C 26 | 0.008 | 1.90 | 0.16 | 0.16 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.27 |
| C 27 | 0.009 | 1.94 | 0.09 | 0.09 | 0.11 | 0.13 | 0.13 | 0.13 | 0.13 | 0.20 |
| C 28 | 0.009 | 1.90 | 0.15 | 0.16 | 0.18 | 0.18 | 0.20 | 0.20 | 0.20 | 0.26 |
| C 29 | 0.008 | 1.93 | 0.12 | 0.12 | 0.13 | 0.13 | 0.15 | 0.15 | 0.15 | 0.25 |
| C 30 | 0.009 | 1.97 | 0.10 | 0.11 | 0.14 | 0.15 | 0.15 | 0.15 | 0.15 | 0.22 |
| Average | | | 0.11 | 0.11 | 0.14 | 0.15 | 0.16 | 0.16 | 0.16 | 0.23 |
| Range | | | 0.06 | 0.06 | 0.11 | 0.13 | 0.13 | 0.13 | 0.13 | 0.18 |
| | | | 0.16 | 0.16 | 0.18 | 0.18 | 0.20 | 0.20 | 0.20 | 0.27 |

TABLE A32 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 2024-T3 BARE/2024-T3 BARE - WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0-1.5 Volt Phosphoric Acid Anodize/A1444B Paste Adhesive Cured at 250-260F for 2-1/2 Hours

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| O 25 | 0.004 | 2.51 | 0.0 | 0.02 | 0.03 | 0.03 | 0.15 | 0.15 | 0.15 | 0.30 |
| O 26 | 0.012 | 2.49 | 0.0 | 0.0 | 0.0 | 0.0 | 0.05 | 0.05 | 0.05 | 0.18 |
| O 27 | 0.011 | 2.56 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.14 |
| O 28 | 0.013 | 2.52 | 0.0 | 0.0 | 0.0 | 0.0 | 0.05 | 0.05 | 0.05 | 0.27 |
| O 29 | 0.011 | 2.44 | 0.07 | 0.07 | 0.07 | 0.10 | 0.10 | 0.10 | 0.10 | 0.20 |
| O 30 | 0.010 | 2.55 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.20 |
| Average | | | 0.0 | 0.02 | 0.02 | 0.02 | 0.06 | 0.06 | 0.06 | 0.22 |
| Range | | | 0.01 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.14 |
| | | | 0.07 | 0.07 | 0.07 | 0.10 | 0.15 | 0.15 | 0.15 | 0.30 |

TABLE A33 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 2024-T3 BARE/2024-T3 BARE PABST SYSTEM

ADHESIVE SYSTEM: 10-15 Volt Phosphoric Acid Anodize/BR-127 Primer/FM 73 Mat Adhesive

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| K 25 | 0.005 | 2.13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K 26 | 0.006 | 2.12 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| K 27 | 0.006 | 2.12 | 0.03 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| K 28 | 0.007 | 2.12 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K 29 | 0.008 | 2.05 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| K 30 | 0.006 | 2.22 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Average | | | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 |
| Range | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | 0.06 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |

TABLE A34 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 7075-T6 BARE/7075-T6 BARE - FPL BONDING SYSTEM

ADHESIVE SYSTEM: FPL Etch/BR-127 Primer/FM 123-2 Mat Adhesive

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| D 25 | 0.010 | 2.00 | 0.10 | 0.11 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.16 |
| D 26 | 0.007 | 2.01 | 0.03 | 0.08 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.16 |
| D 27 | 0.009 | 1.99 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.16 |
| D 28 | 0.010 | 1.95 | 0.12 | 0.12 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.16 |
| D 29 | 0.009 | 2.02 | 0.0 | 0.05 | 0.07 | 0.08 | 0.08 | 0.08 | 0.08 | 0.10 |
| D 30 | 0.010 | 1.97 | 0.11 | 0.14 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.16 |
| Average | | | 0.08 | 0.11 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.15 |
| Range | | | 0.0 | 0.05 | 0.07 | 0.08 | 0.08 | 0.08 | 0.08 | 0.10 |
| | | | 0.11 | 0.14 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.16 |

TABLE A35 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 7075-T6 BARE/7075-T6 BARE - WELDBOND SYSTEM

ADHESIVE SYSTEM: 1.0-1.5 Volt Phosphoric Acid Anodize/Al444B Paste Adhesive Cured at 270-290 F For 1 Hour

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| P 25 | 0.010 | 2.39 | 0.0 | 0.0 | 0.0 | 0.0 | 0.03 | 0.03 | 0.03 | 0.18 |
| P 26 | 0.013 | 2.34 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.11 |
| P 27 | 0.010 | 2.43 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.10 |
| P 28 | 0.011 | 2.73 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.06 |
| P 29 | 0.010 | 2.48 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.11 |
| P 30 | 0.009 | 2.81 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | Average | 0.0 | 0.0 | 0.0 | 0.0 | 0.005 | 0.005 | 0.005 | 0.09 |
| | | Range | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.03 | 0.03 | 0.03 | 0.18 |

TABLE A36 WEDGE TEST DATA - 95-100% RELATIVE HUMIDITY EXPOSURE - 7075-T6 BARE/7075-T6 BARE - PABST SYSTEM

ADHESIVE SYSTEM: 10-15 Volt Phosphoric Acid Anodize/BR-127 Primer/FM 73 Mat Adhesive

EXPOSURE STARTED: 12 June 1978

| Specimen Code | Bondline Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Days) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 4 | 11 | 15 | 30 | 45 | 60 | 90 |
| L 25 | 0.006 | 2.18 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.06 |
| L 26 | 0.006 | 2.06 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.05 |
| L 27 | 0.008 | 2.10 | 0.02 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| L 28 | 0.009 | 2.13 | 0.0 | 0.05 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.05 |
| L 29 | 0.008 | 2.17 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| L 30 | 0.007 | 2.13 | 0.0 | 0.05 | 0.05 | 0.05 | 0.08 | 0.08 | 0.08 | 0.08 |
| | | Average | 0.0 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.05 |
| | | Range | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | 0.02 | 0.05 | 0.05 | 0.05 | 0.08 | 0.08 | 0.08 | 0.08 |

TABLE A37 WEDGE TEST DATA – SEA COAST EXPOSURE – 2024-T3 ALCLAD/7075-T6 BARE

WELDBOND SYSTEM WITH PRIMER BR-127

ADHESIVE SYSTEM: 1.0-1.5 Volt Phosphoric Acid Anodize/BR-127/A1444B

EXPOSURE STARTED: 1 February 1979

| Specimen Code | Bond Line Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| C1 | 0.005 | 2.30 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | | | | | | | |
| C2 | 0.005 | 2.27 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | | | | | | | |
| C3 | 0.006 | 2.32 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | | | | | |
| C4 | 0.005 | 2.36 | 0.0 | 0.0 | 0.0 | 0.02 | 0.02 | | | | | | | |
| C5 | 0.005 | 2.26 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | | | | | | | |
| C6 | 0.006 | 2.28 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | | | | | |
| C7 | 0.009 | 2.27 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | | | | | |
| C8 | 0.004 | 2.28 | 0.0 | 0.09 | 0.09 | 0.09 | 0.09 | | | | | | | |
| C9 | 0.005 | 2.30 | 0.0 | 0.05 | 0.05 | 0.05 | 0.05 | | | | | | | |
| C10 | 0.006 | 2.55 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | Average | | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | | | | | | | |
| | Range | | 0.0<br>0.20 | 0.0<br>0.20 | 0.0<br>0.20 | 0.0<br>0.20 | 0.0<br>0.20 | | | | | | | |

TABLE A38 WEDGE TEST DATA – SALT FOG EXPOSURE – 2024-T3 ALCLAD/7075-T6 BARE

WELDBOND SYSTEM WITH PRIMER BR-127

ADHESIVE SYSTEM: 1.0-1.5 Volt Phosphoric Acid Anodize/BR-127/A1444B

EXPOSURE STARTED: 10 October 1978

| Specimen Code | Bond Line Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time (Months) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 4-1 | 0.008 | 2.08 | 0.15 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | | | | | |
| 4-2 | 0.012 | 2.15 | 0.10 | 0.15 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | | | | | |
| 4-3 | 0.012 | 2.11 | 0.05 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | | | | | |
| 4-4 | 0.010 | 2.25 | 0.05 | 0.10 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | | | | | |
| 4-5 | 0.009 | 2.34 | 0.0 | 0.05 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | (1) | | | | |
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| Average | | | 0.07 | 0.13 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | | | | | |
| Range | | | 0.0<br>0.15 | 0.05<br>0.20 | 0.15<br>0.20 | 0.15<br>0.20 | 0.15<br>0.20 | 0.15<br>0.20 | 0.15<br>0.20 | | | | | |

(1) Discontinued and split open to show 100 percent cohesive failure.

TABLE A39 WEDGE TEST DATA FOR WELDBOND SPECIMENS WITH WELDS – 2024-T3 ALCLAD/ 7075-T6 BARE

ADHESIVE SYSTEM: 1.0 - 1.5 Volt Phosphoric Acid Anodize/A1444B Paste Adhesive With One Spot Weld Centered 3 Inches From End of Specimen

EXPOSURE STARTED: 9 January 1979 in 5% Salt Fog at 95F

| Specimen Code | Bond Line Thickness (Inch) | Initial Crack Length (Inch) | Wedge Crack Growth (Inch) Exposure Time Days 2 | 6 | 13 | 20 | Months 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WB-1 | 0.005 | 2.21 | 0.10 | 0.35 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | (1) | | |
| WB-2 | 0.005 | 2.23 | 0.10 | 0.40 | 0.50 | 0.55 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | |
| WB-3 | 0.005 | 2.28 | 0.0 | 0.25 | 0.40 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | |
| WB-4 | 0.005 | 2.27 | 0.07 | 0.50 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | |
| WB-5 | 0.005 | 2.25 | 0.08 | 0.45 | 0.50 | 0.50 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | |
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| Average | | | 0.07 | 0.39 | 0.52 | 0.57 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | |
| Range | | | 0.0 | 0.25 | 0.40 | 0.50 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | |
| | | | 0.10 | 0.50 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 | |

(1) Specimen was removed after four months and pried open. Thirty percent interface corrosion was observed on the 2024-T3 alclad surface in addition to the 100 percent adhesive failure along this surface.



*U.S.Government Printing Office: 1979 — 657-002/190